

N72-27912

(NASA-CR-123719) SPACE STATION EXECUTIVE  
SUMMARY (McDonnell-Douglas Astronautics  
Co.) Apr. 1972 75 p

CSSL 22B

Unclass

G3/31 15650

5.15

# SPACE STATION

## EXECUTIVE SUMMARY

Reproduced by  
**NATIONAL TECHNICAL  
INFORMATION SERVICE**  
U S Department of Commerce  
Springfield VA 22151

McDONNELL DOUGLAS



# SPACE STATION

## EXECUTIVE SUMMARY

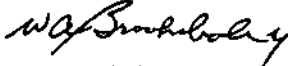
**MSFC-DPD-235/DR NO. MA-04**

**CONTRACT NAS8-25140**

**APRIL 1972**

**MDC G2727**

APPROVED BY



**W. A. BROOKSBANK, JR.**  
MANAGER  
SPACE STATION TASK TEAM

APPROVED BY



**T. D. SMITH**  
VICE PRESIDENT - PROGRAM MANAGER  
SPACE STATION

*Details of illustrations in  
this document may be better  
studied on microfiche.*

**MCDONNELL DOUGLAS ASTRONAUTICS COMPANY-WEST**

5301 Bolsa Avenue, Huntington Beach, CA 92647

**MCDONNELL DOUGLAS**



**CORPORATION**

## PREFACE

---

The work described in this document was performed under the Space Station Phase B Extension Period Study (Contract NAS8-25140). The purpose of the extension period has been to develop the Phase B definition of the Modular Space Station. The modular approach selected during the option period (characterized by low initial cost and incremental manning) was evaluated, requirements were defined, and program definition and design were accomplished to the depth necessary for departure from Phase B.

The initial 2-1/2-month effort of the extension period was used for analyses of the requirements associated with Modular Space Station Program options. During this time, a baseline, incrementally manned program and attendant experiment program options were derived. In addition, the features of the program that significantly affect initial development and early operating costs were identified, and their impacts on the program were assessed. This assessment, together with a recommended program, was submitted for NASA review and approval on 15 April 1971.

The second phase of the study (15 April to 3 December 1971) consists of the program definition and preliminary design of the approved Modular Space Station.

This report is submitted as Data Requirement MA-04.

Preceding page blank

**DATA REQUIREMENTS (DR'S)**  
**MSFC-DPD-235/DR NUMBERS**  
 (Contract NAS8-25140)

Category	Designation	DR Number	Title
Configuration Management	CM	CM-01	Space Station Program (Modular) Specification
		CM-02	Space Station Project (Modular) Specification
		CM-03	Modular Space Station Project Part 1 CEI Specification
		CM-04	Interface and Support Requirements Document
Program Management	MA	MA-01	Space Stations Phase B Extension Study Plan
		MA-02	Performance Review Documentation
		MA-03	Letter Progress and Status Report
		MA-04	Executive Summary Report
		MA-05	Phase C/D Program Development Plan
		MA-06	Program Option Summary Report
Manning and Financial	MF	MF-01	Space Station Program (Modular) Cost Estimates Document
		MF-02	Financial Management Report
Mission Operations	MP	MP-01	Space Station Program (Modular) Mission Analysis Document
		MP-02	Space Station Program (Modular) Crew Operations Document
		MP-03	Integrated Mission Management Operations Document

**DATA REQUIREMENTS (DR'S)**  
**MSFC-DPD-235/DR NUMBERS**  
**(Contract NAS8-25140)**

Category	Designation	DR Number	Title
Technical Description	SE	SE-01	Modular Space Station Concept
		SE-02	Information Management System Study Results Documentation
		SE-03	Technical Summary
		SE-04	Modular Space Station Detailed Preliminary Design
		SE-06	Crew/Cargo Module Definition Document
		SE-07	Modular Space Station Mass Properties Document
		SE-08	User's Handbook
		SE-10	Supporting Research and Technology Document
		SE-11	Alternate Bay Sizes

---

## CONTENTS

---

	GLOSSARY OF TERMS . . . . .	iv
	INTRODUCTION AND SUMMARY . . . . .	1
Section 1	DESIGN CHARACTERISTICS . . . . .	7
	Configuration Descriptions . . . . .	7
	Subsystem Definitions . . . . .	20
	Long-Life Design . . . . .	31
	Safety Features . . . . .	32
Section 2	EXPERIMENT PROGRAM (ISS/GSS) . . . . .	35
	Experiment Definition and Allocation . . . . .	35
	Experiment Schedules . . . . .	36
	Experiment Operations . . . . .	38
Section 3	OPERATIONS . . . . .	41
	Mission Support Operations . . . . .	41
	Flight Operations . . . . .	44
Section 4	PROGRAM DESCRIPTION . . . . .	51
	Program Schedule . . . . .	52
	Specifications and Plans . . . . .	55
	Program Costs . . . . .	59
Section 5	RESEARCH IMPLICATIONS . . . . .	63

---

GLOSSARY

---

ATP	Authority to proceed
B-Eng	Bioengineering
B-Env	Bioenvironment
B-Res	Bioresearch
C	Control
CCM	Crew/cargo module
CEI	Contract end item
CMG	Control moment gyro
CRT	Cathode ray tube
DDT&E	Design, development, test, and engineering
DMS	Data management subsystem
DRS	Data relay satellite
EC/LS	Environmental control and life support
EI	Experiment integration
EVA	Extravehicular activity
FDM	Frequency-division multiplex
FIT	Flight integration tool
FM	Functional model
FPE	Functional program element
FY	Fiscal year
GNC	Guidance, navigation, and control
GPL	General purpose laboratory
GSE	Ground support equipment
GSS	Growth Space Station
IOC	Initial operating capability
IR	Infrared
IS	Information system
ISS	Initial Space Station
IVA	Intravehicular activity
LOG M	Logistics module
LRU	Lowest replaceable unit
M&S	Materials and structure

---

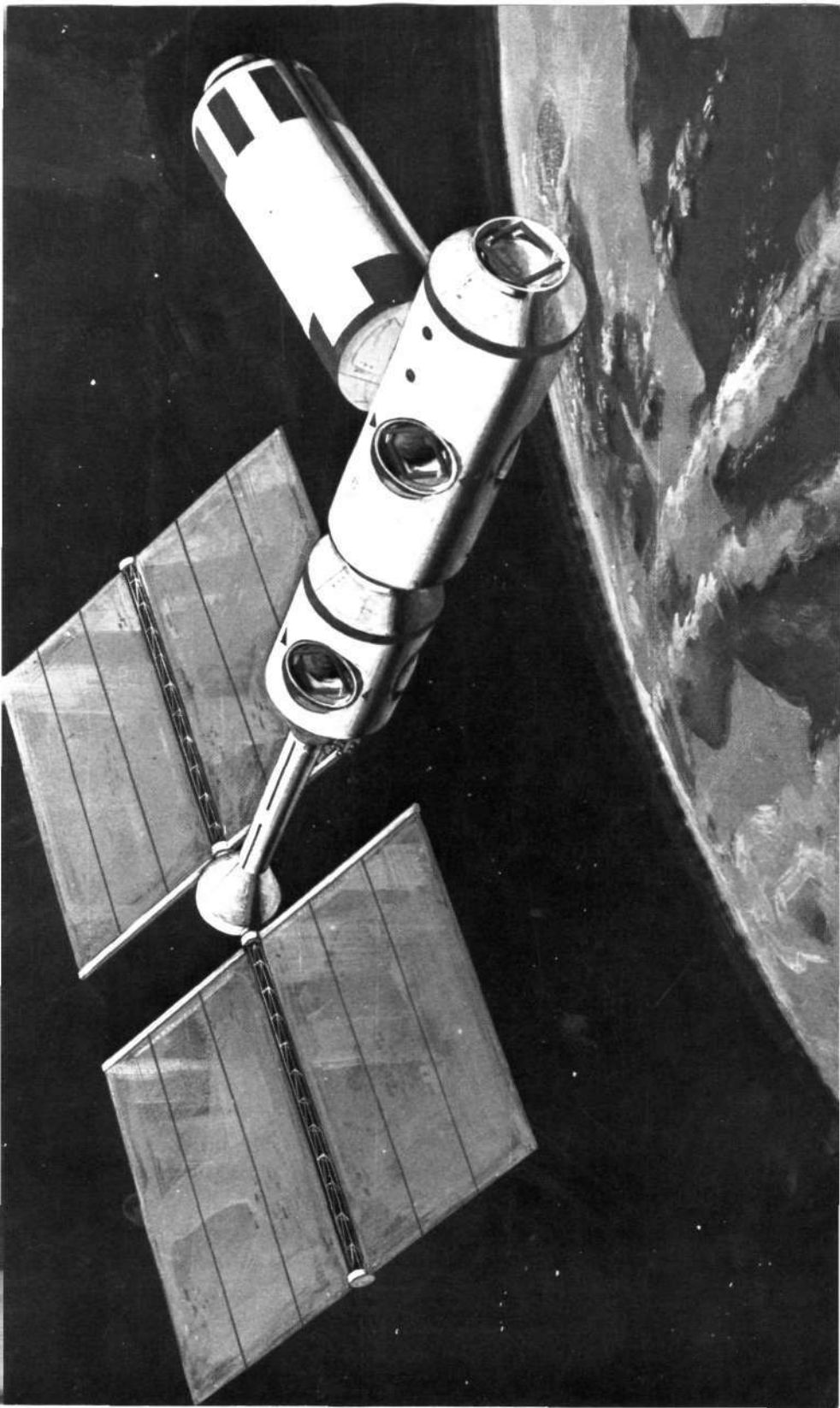
## GLOSSARY (Continued)

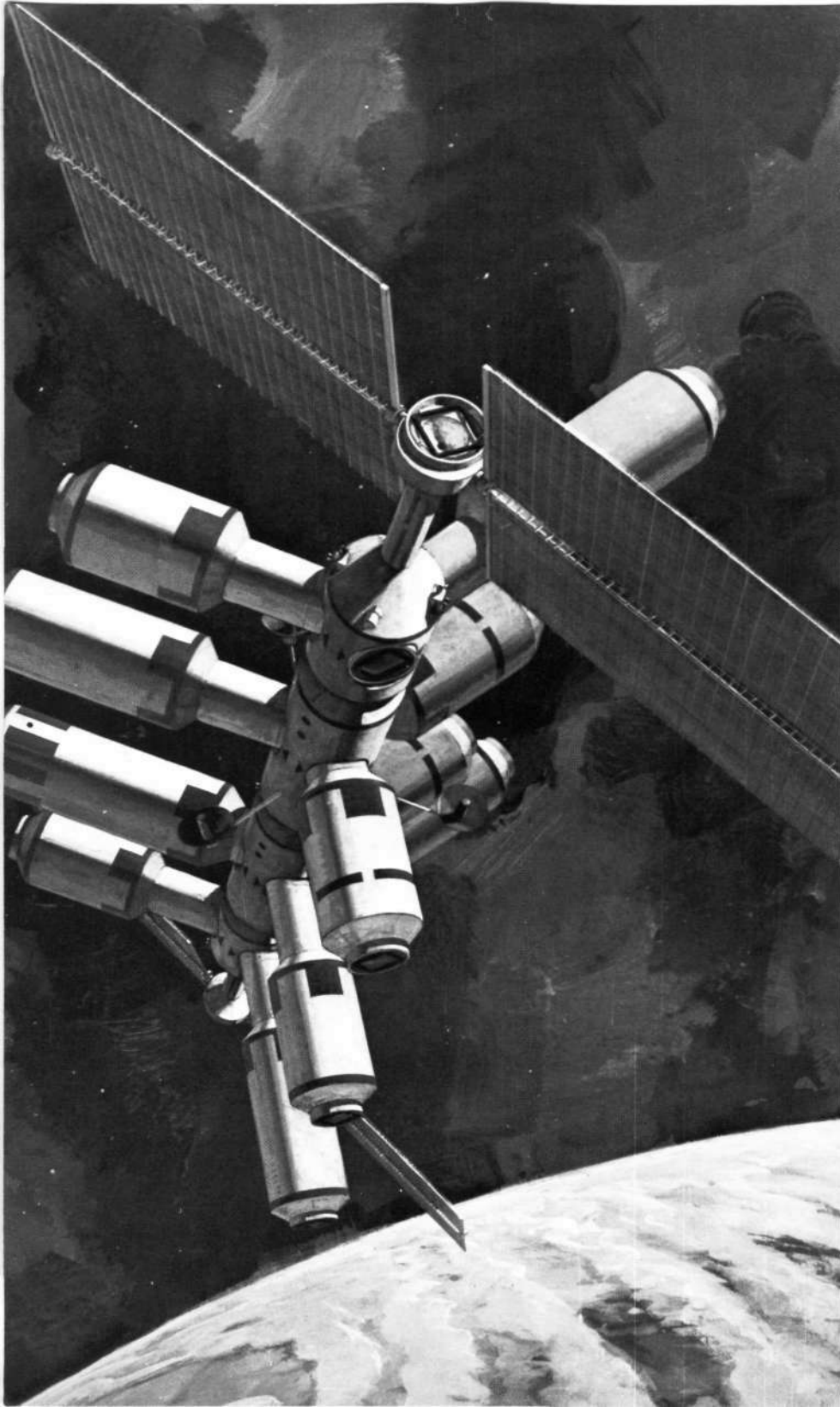
---

MDAC	McDonnell Douglas Astronautics Company
NASA/MSFC	National Aeronautics and Space Administration/ Marshall Space Flight Center
nmi	Nautical mile
OBCO	Onboard checkout
P	Power
PI	Principal investigator
PLSS	Portable life support system
RAM	Research and applications module
RDAU	Remote data acquisition unit
SRT	Supporting research and technology
TDM	Time-division multiplex
UV	Ultraviolet
VAC	Volts alternating current
VDC	Volts direct current

---







---

## INTRODUCTION AND SUMMARY

---

NASA's Space Shuttle System planned for the late 1970's provides the transportation mode necessary to establish a realistic manned Modular Space Station laboratory in long-term Earth orbit. Using the shuttle for module delivery to orbit, support of orbital assembly, logistics support, and return of scientific data, this laboratory will provide the scientific community with many advantages, and the United States with a platform for data collection on subjects of national concern such as ecology, weather prediction, and medical research. Its orbital location will provide an ideal environment for both Earth and space observations.

A basic objective of this study was the definition of an on-orbit research and development laboratory that could accommodate a broad base of space experiment activities at a cost significantly below the costs required for individual on-orbit experiment support. The Modular Space Station is just such a laboratory. It provides the basic services—e.g., power and conditioning of the onboard environment, data processing—that one would find in a laboratory facility on Earth.

The Modular Space Station of this study has been designed to provide an on-orbit capability to perform research and applications functions. The assembled station includes a general purpose laboratory (GPL) which provides experiment support equipment and space for research work. This laboratory concept reduces the costs of specific research and application activities by providing common supporting resources, thus minimizing the complexity and eliminating the duplication of equipment that would otherwise be required. In addition to experiments carried out within the station, the laboratory supports operation of experiments conducted in separate modules that are either docked to the station or are flying free of it but are controlled from it.

The Space Station, in conjunction with research and applications modules (RAM's), is capable of satisfying a broad scope of research and applications objectives. The objectives may be realigned and modified as the missions

progress and experiment results are obtained. Typical selected objectives are shown in Table 1. These objectives are balanced with respect to scientific and applications activities and could be accomplished without free-flying modules in a minimal-cost experiment program.

Space Station operations will be largely self-contained so that the onboard crew may efficiently allocate its time for experiment/station activities. Ground activities will ordinarily be limited to long-range planning, logistics control, and experiment program support.

The three modules of the Initial Space Station (ISS), which will accommodate six men, will be individually delivered to orbit by three shuttle launches and docked in space. A two-man activation crew accompanies each ISS module delivery to perform predetermined checkout activities for the module during a five-day shuttle on-orbit stay. The activation crew then returns to Earth with the shuttle orbiter.

An artist's concept of the assembled ISS configuration is shown in the frontispiece. The power/subsystems module will be launched first, followed at 30-day intervals by the crew/operations module and the general purpose laboratory module (Figure 1). The assembled configuration will accommodate a crew of six, and support as many as four RAM's. Resupply, crew rotation, and experiment changes and additions are accomplished by shuttle flights using logistics modules for transport and storage of cargo. One logistics module remains attached to the Space Station at all times.

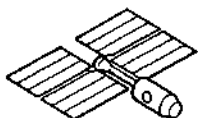
The fourth shuttle flight provides the ISS with its initial crew of two men and satisfies the initial logistics requirements. Two more crewmen are transported to the ISS 30 days later aboard the fifth shuttle launched. Thirty days after that, the sixth shuttle flight delivers two more crew members to the ISS, bringing it to its crew operational level of six men. In addition to crew augmentation, the fifth and sixth shuttle flights are used to replace logistics modules. The replacement modules contain spares, expendables, and experiment supplies.

The first crew-rotation shuttle flight is scheduled for the seventh shuttle launch. Two crewmen are delivered to the ISS to replace the initial two-man team. A shuttle flight is scheduled every 30 days thereafter during ISS operations, thus providing two crewmen on a nominal crew-rotation cycle of 90 days, and delivering cargo as appropriate. Approximately four of the

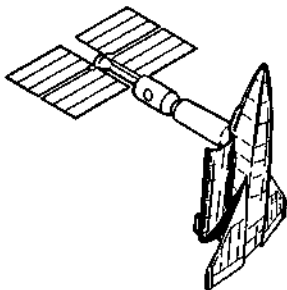
**Table 1**  
**TYPICAL RESEARCH AND APPLICATIONS OBJECTIVES**

Experiment Discipline	Typical Objectives
Earth surveys	<ul style="list-style-type: none"> <li>• Land-use identification of major crop, forest, and range types</li> <li>• Recognition of soil types, moisture content, size, vigor, and yield of crops</li> <li>• Geometry of entire Earth</li> <li>• Location of mineral and oil deposits, and measurement of snow cover and flood water</li> <li>• Water- and atmosphere-pollution detection, control</li> <li>• Fish-population distribution and ocean-current forecasts</li> </ul>
Communications/ navigation	<ul style="list-style-type: none"> <li>• Ionospheric effects on radio-wave propagation</li> <li>• Millimeter-wave technology</li> <li>• Satellite navigation techniques</li> <li>• Global air-traffic surveillance and control</li> </ul>
Physics	<ul style="list-style-type: none"> <li>• Chemical reactions in zero gravity</li> <li>• Atmospheric processes</li> <li>• Origin of cosmic-ray particles</li> </ul>
Materials sciences	<ul style="list-style-type: none"> <li>• Superior glasses and thin films</li> <li>• New biological products</li> </ul>
Space astronomy	<ul style="list-style-type: none"> <li>• Ultraviolet sky survey</li> <li>• Spectra of strong UV sources</li> </ul>
Life sciences	<ul style="list-style-type: none"> <li>• Changes in circulatory function due to weightlessness</li> <li>• Role of gravity and Earth-lunar periodicities in basic biological processes</li> </ul>
Technology	<ul style="list-style-type: none"> <li>• Advanced space systems</li> </ul>

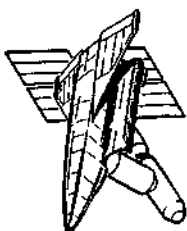
① 1 OCT 1980\*  
POWER  
MODULE NO. 1



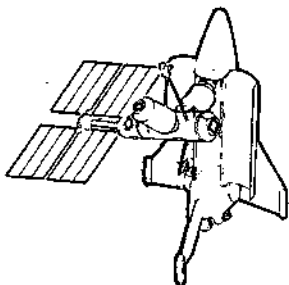
② 31 OCT 1980\*  
CREW  
MODULE NO. 2



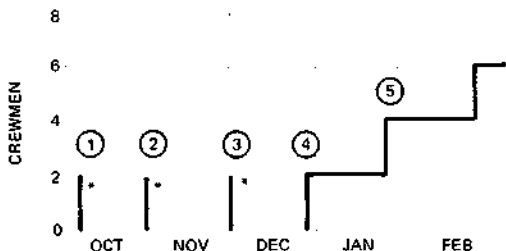
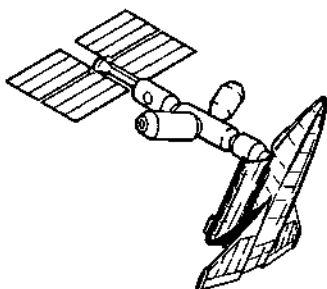
③ 30 NOV 1980\*  
GPL  
MODULE



④ DEC 1980  
LOGISTICS  
MODULE NO. 1



⑤ JAN 1981  
LOGISTICS  
MODULE NO. 2



SIX CREWMEN,  
TWO CREWMEN ROTATE  
EVERY 30 DAYS

\*TWO-MAN ACTIVATION CREW  
RETURN WITH SHUTTLE

**Figure 1. Initial Space Station Buildup**

station crew will devote their time to experiment operations, while the remaining two crewmen will be responsible for overall station operations and support.

The shuttle baseline used for this study limited the number of passengers per shuttle flight to two. An increased passenger-carrying capability on the part of the shuttle would enhance the effectiveness of the Space Station Program by permitting earlier attainment of on-orbit operational capability, and would increase the logistics support available per shuttle launch.

To achieve the twelve-man Growth Space Station (GSS) capability, two modules (power/subsystem and crew/operations) are added to the ISS cluster. These modules are identical in design to those deployed for the initial station. The growth configuration is capable of accommodating as many as nine attached or free-flying RAM's, and three logistics modules (Figure 2).

The Modular Space Station effectively complements the Space Shuttle System because it is a permanent orbital platform, whereas the shuttle is efficient for transportation and short-duration missions. This study has produced data for planning and initiating the design and development required to achieve the desired on-orbit laboratory capability.

The sections that constitute the body of this study summary describe the design characteristics of the Modular Space Station, its attendant experiment program, the operational concepts needed to support 10 years of orbital activity, and the program's costs and schedules. A section has been included that summarizes specific technology areas that warrant early attention.

The results summarized here are detailed in a series of 18 report documents that were prepared and submitted during the course of this study.

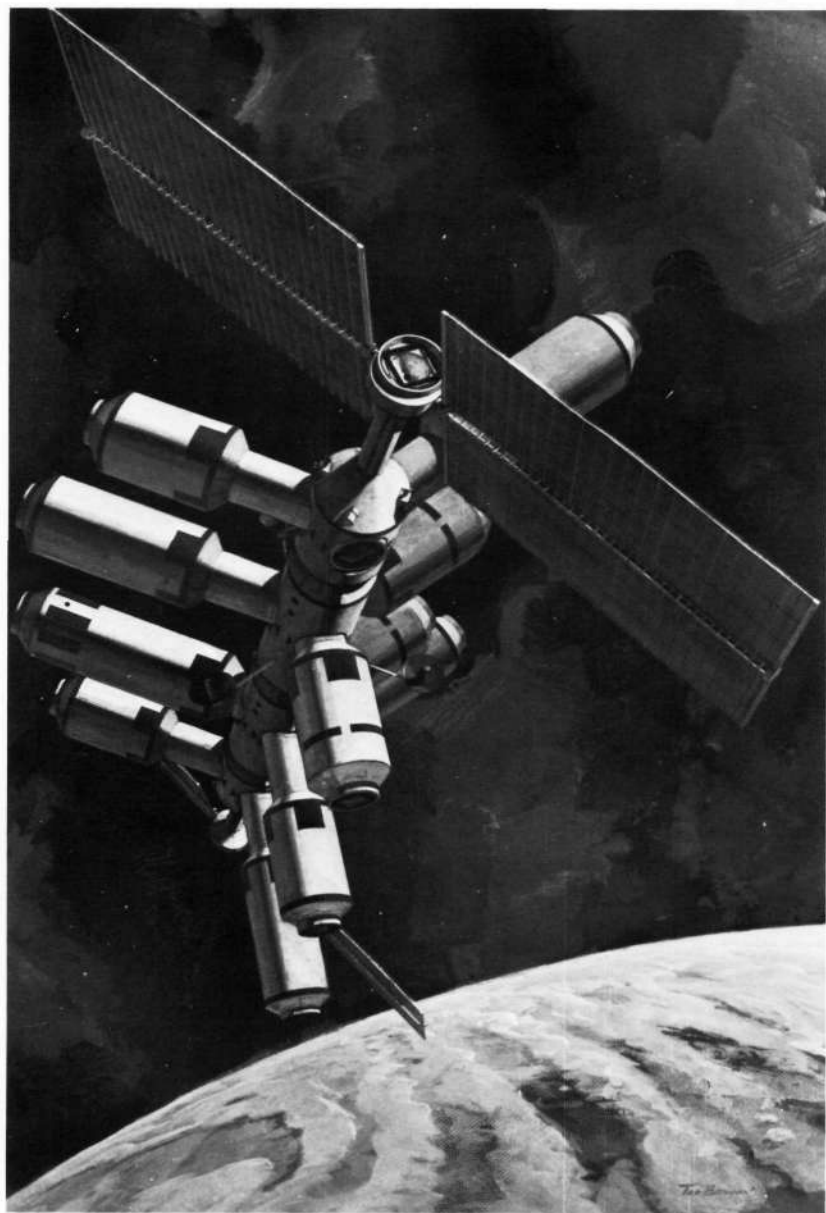


Figure 2. Growth Space Station



---

## Section 1

### DESIGN CHARACTERISTICS

---

The Modular Space Station Phase B Definition Study was addressed primarily to the definition of an Initial Space Station (ISS) capability; however, the requirements for a Growth Space Station (GSS) were applied to its definition and preliminary design.

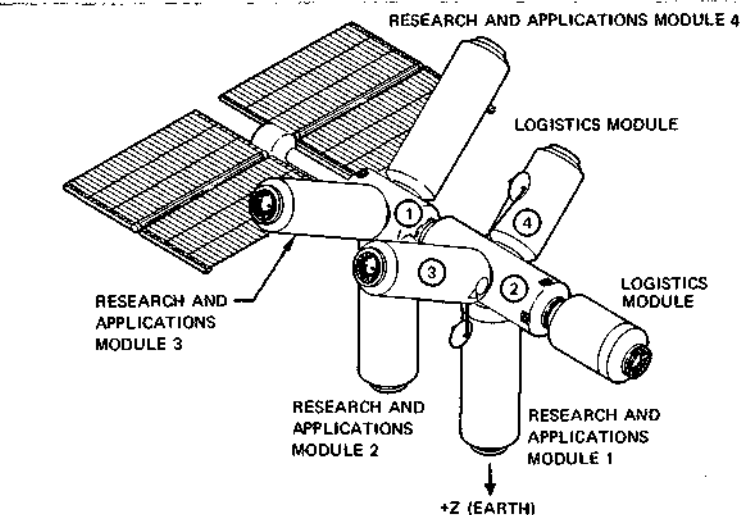
#### CONFIGURATION DESCRIPTIONS

The basic modules that comprise the Initial Space Station are as follows:

- A power/subsystems module containing the power source and subsystem components that support experiments and operations.
- A crew/operations module which provides the housekeeping facilities for the crew, and the control center for station/experiment operations.
- A general purpose laboratory (GPL) module which contains the resources and volume necessary for accommodating integral experiments or supporting experiments housed in attached and free-flying modules.

This modular assemblage is augmented with logistics modules and research and applications modules (RAM's). The former provide the logistics support necessary to sustain long-term orbital operations, while the latter provide modular accommodations for those experiments which cannot be housed within the Space Station GPL. The mode of accommodation for the experiments, i.e., integral, attached, or free-flying, is discussed in Section 2. Figure 3 illustrates the on-orbit configuration of the Initial Space Station with a full complement of modules. The basic configuration consists of the three modules described above (designated in the figure with the numbers 1, 2, and 3). Six docking ports are available, two of which are used for resupply by shuttle-transported logistics modules.

The modules are arranged as follows. The power/subsystems module is on the forward end of the cluster. The crew/operations module is docked to the aft end of the power/subsystems module. Both the power/subsystems



LAUNCH SEQUENCE/MODULE	1	2	3	4
PRIMARY FUNCTION	POWER/ SUBSYSTEM	CREW/ OPERATIONS	GENERAL PURPOSE LABORATORY	LOGISTICS MODULE

**Figure 3. Initial Space Station (Maximum Cluster Configuration)**

module and the crew/operations module have three radial docking ports spaced at 120 degrees on centers. The general purpose laboratory module is radially docked to the crew/operations module at the upper left-hand port (looking forward). Logistic modules are docked alternately at the upper right-hand port and the end port of the crew/operations module. The nadir port on the crew/operations module and three ports on the power/subsystems module are used by research and applications modules. Figure 4 is an inboard profile of the three-module ISS configuration, and includes a logistics module.

The ISS configuration was chosen from a large group of potential module arrangements. The major considerations in this evaluation were cost, crew safety, habitability, efficient accommodation of the experiment program, growth to the 12-man Space Station, and compatibility with the shuttle orbiter during buildup and resupply.

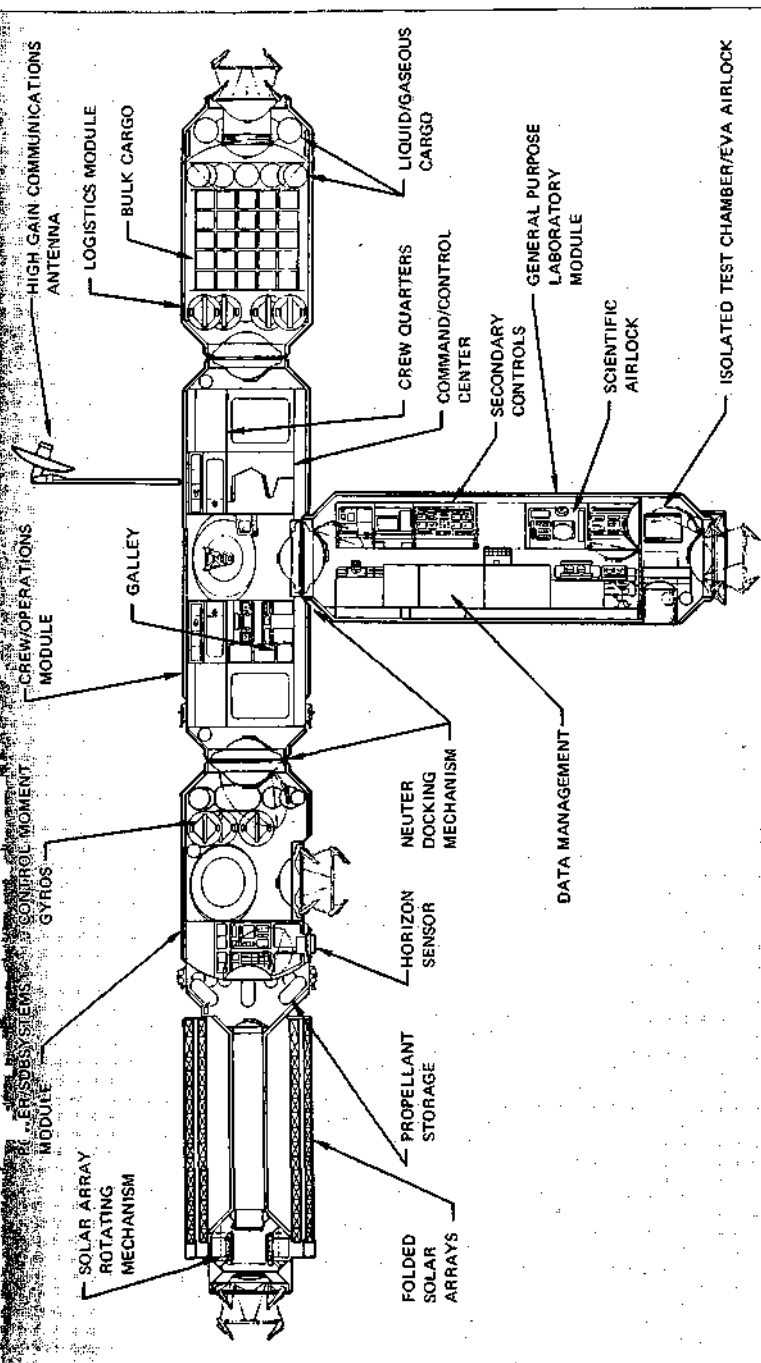


Figure 4. ISS Inboard Profile (With Logistics Module)

The ISS is operational for 5 years in the configuration described above, after which it is augmented by the addition of a second power module and a second crew module. The total capability of this assemblage has been designated as the Growth Space Station, and will continue on-orbit operations for at least an additional 5 years. Figure 5 is an illustration of this GSS configuration. The GSS is capable of supporting a twelve-man crew, and can simultaneously accommodate as many as eight research and applications modules and three logistics or crew/cargo modules. With this augmented capability, the Modular Space Station can now support any reasonable combination of the experiments identified within the Referenced Earth Orbital Research and Applications Investigations Document (Blue Book). The experiment program used as a model to verify this support capability is described in Section 2.

The launch weights of the three basic ISS modules and the logistics module are summarized in Table 2. In each instance, the launch weight is less than the target shuttle payload weight of 20,000 pounds per module. These weight differentials have been designated as "discretionary margins," and provide a pad of between 10 and 20 percent which can be used to accommodate either subsystem weight growth or the addition of components. On completion of orbital assembly, the basic Space Station configuration weighs 48,612 pounds. This mass is subsequently increased to 77,345 pounds by the addition of supplies and equipment transported to orbit by logistics flights.

The modules and their constituent subsystems are described in the subsections that follow.

#### **Power/Subsystems Module**

The power/subsystems module (see Figure 6) contains all subsystems necessary to sustain the ISS cluster until assembly is completed and manning and regular logistics resupply are initiated. It is 14 feet in diameter, 58 feet long, and weighs about 17,513 pounds at launch. The solar array (not shown) has a panel area of 5,300 ft<sup>2</sup>. A pressure compartment 30 feet long incorporates three radial docking ports and houses subsystems as shown. Although it does not contain crew work stations, a shirt-sleeve environment is maintained in this compartment since it is occupied when equipment servicing is required. Control moment gyros (CMG's) and

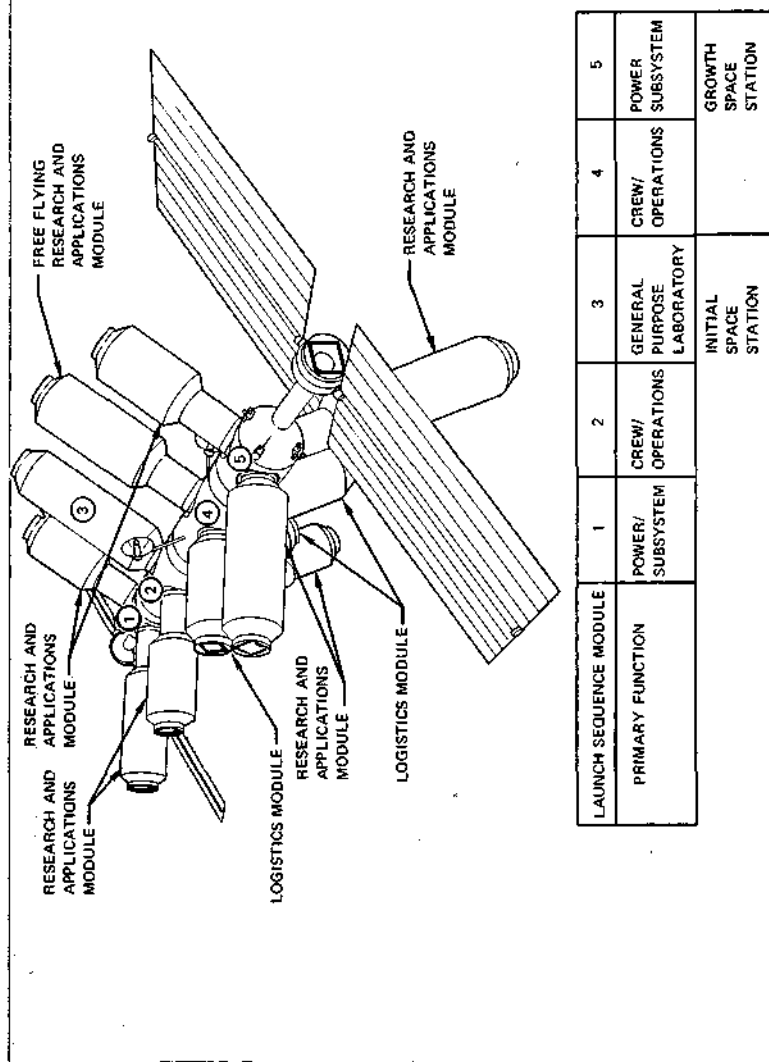


Figure 5. Growth Space Station (Maximum Cluster Configuration)

**Table 2**  
**INITIAL SPACE STATION AND LOGISTIC**  
**MODULE WEIGHT SUMMARY (AT LAUNCH)**

Description	Power/ Subsystems Module	Crew/ Operations Module	General Purpose Laboratory Module	Logistics Module
	Weight (lb)	Weight (lb)	Weight (lb)	Weight (lb)
Structure	3,308	3,480	3,783	2,647
Meteoroid/thermal protection	2,108	2,036	2,002	1,104
Docking provisions	1,539	1,539	615	616
Propulsion	736	316	54	158
Prime power	4,625	15	15	—
Power conditioning and distribution	673	287	288	77
Electronics	1,386	2,523	2,063	456
Wiring	580	794	1,032	165
Atmospheric and thermal control	831	1,287	1,269	740
Crew life support and interiors	425	2,568	665	435
Crew equipment and crew	—	—	—	—
General Purpose Laboratory and experimental provisions	—	—	3,163	—
Residuals	649	684	648	240
Reserves	223	—	—	—
Inflight losses	530	—	—	—
Minimum-launch total	17,513	15,529	15,587	6,638
Cargo	—	—	—	11,012
Discretionary margin	2,487	4,471	4,413	2,350
Target	20,000	20,000	20,000	20,000

atmosphere supply tanks are installed on orbit after being transferred from the logistics module in which they were transported. The propulsion system is isolated from the remainder of the compartment by a pressure-tight bulkhead. A docking port on the solar array end allows on-orbit handling of the module if required.

### **Crew/Operations Module**

The crew/operations module (Figure 7) is docked to the power/subsystems module. It provides for the habitability of the flight crew and contains the control center for the Modular Space Station. The module is 14 feet in diameter, 45 feet long, and weighs about 15,529 pounds at launch. The internal arrangement is optimized for zero-gravity operations. Individual quarters for three crew members and a complete hygiene facility are located at each end. This arrangement was selected to permit flexibility and to enhance multishift operations. The operations control station is located at one end of the wardroom and the galley at the other end. Three radial docking ports are located at the midpoint of the module to maximize clearance between attached modules during shuttle docking operations.

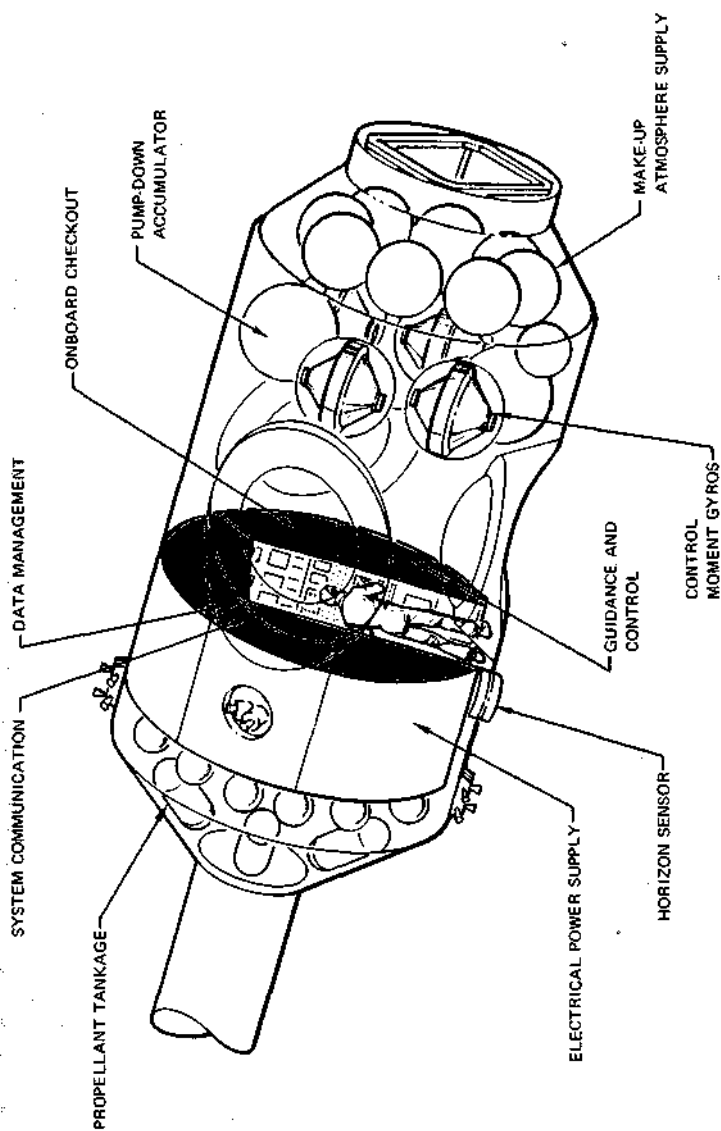


Figure 6. Power/Subsystems Module

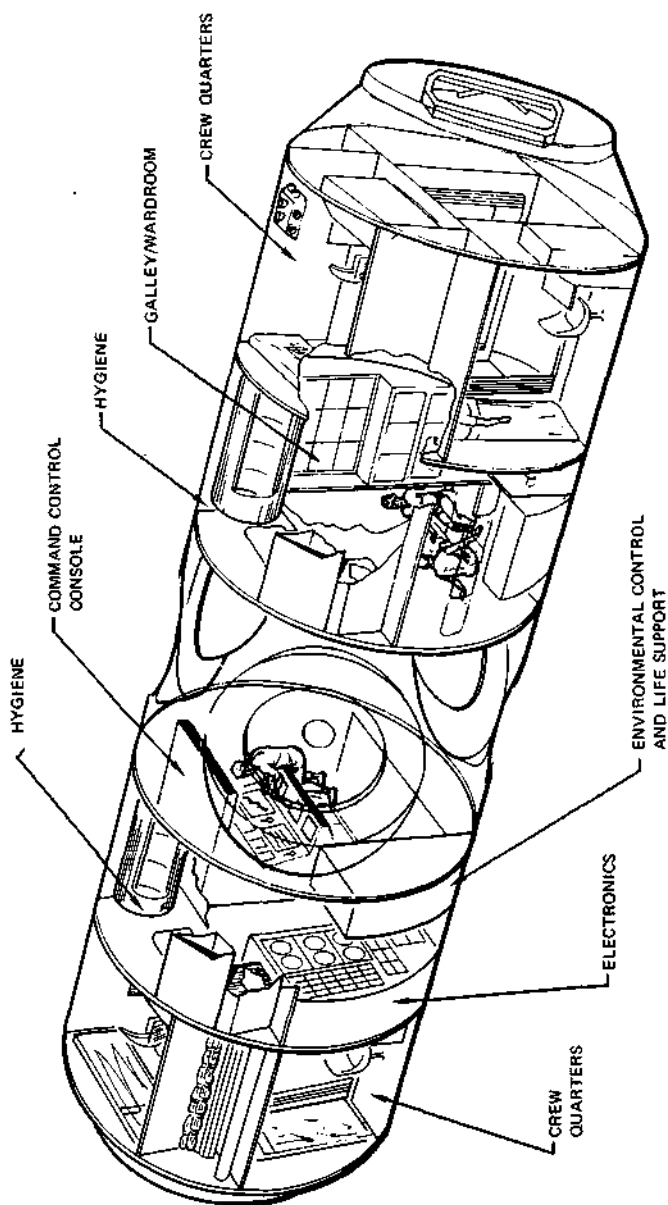


Figure 7. Crew/Operations Module



### **General Purpose Laboratory Module**

The general purpose laboratory (GPL) module is docked to the crew/operations module. Its external configuration is similar to that of the crew/operations module, except that it does not have radial docking ports. The GPL module weighs 15,587 pounds at launch.

The GPL provides the capability to perform experiments and to support other experiments in research and applications modules. Specifically, it has (1) space to accommodate experiments, (2) equipment to perform experiments, and (3) equipment for calibration, analysis, processing, and control of experiment equipment and data. The equipment in the GPL has common application to a number of experiments and is grouped into seven laboratories and facilities. In addition to laboratories and facilities, the GPL houses data management and environmental control and life support (EC/LS) equipment. The experiment-control console in the GPL also functions as a backup control station to the primary control console located in the crew/operations module.

The functions of each of the seven GPL laboratories and facilities are illustrated in Figure 8 and described in the following subsections.

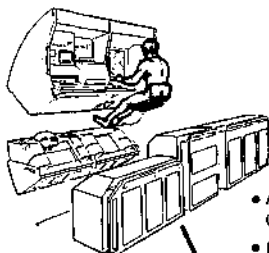
### **Data Evaluation Facility**

The data evaluation facility includes equipment related to or associated with film video, analog, and digital data, and the handling, processing, and evaluation of such data. It is both an experiment and operations support facility and, as such, provides services to all experiments and subsystems. The data evaluation facility is an integral part of the data management subsystem.

### **Mechanical Sciences Laboratory**

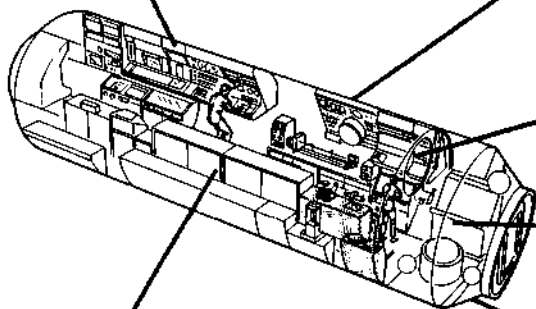
Many types of mechanical, electromechanical, and chemical functions can be accommodated by the equipment in the mechanical sciences laboratory. This laboratory features a laminar-flow glove box for heavy-duty and light-duty repair, replacement, purging, and cleaning of experiment equipment subassemblies. Other equipment in this laboratory is typical of that in a metallurgical research laboratory and is used for performance and analysis of material sciences experiments.

**DATA EVALUATION  
FACILITY**

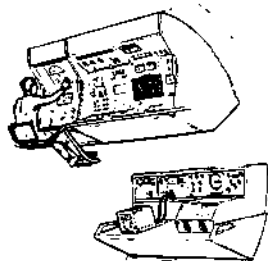


- ANALYZE, DIGITIZE, AND CALIBRATE FILM
- ELECTRONIC IMAGE PROCESSING

Reproduced from  
best available copy.

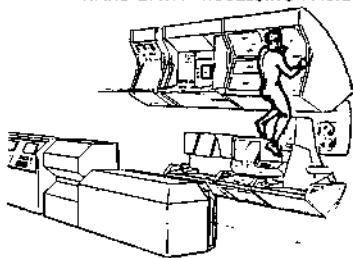


**ELECTRONIC/ELECTRICAL  
LABORATORY**



- ELECTRONIC CALIBRATION
- CHECKOUT AND DIAGNOSTIC STIMULI
- MULTI-INSTRUMENT TEST STATION
- ELECTRONIC WORK BENCH

**HARD DATA PROCESSING FACILITY**



- BLACK-AND-WHITE, COLOR FILM PROCESSING
- EMULSION PLATE PROCESSING
- MICROFILM
- FILM STORAGE

**Figure 8. General Purpose Laboratories and Facilities**



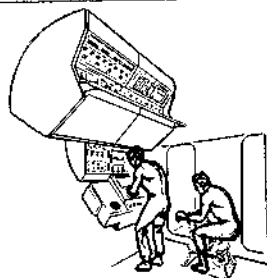
6-MAN STATION

12-MAN STATION

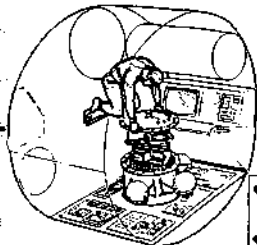
VOLUME AVAILABLE  
FOR GROWTH

- CALIBRATE INSTRUMENTS
- OPTICAL ANALYSIS
- SCIENTIFIC AIRLOCK
- SUPPORT OPTICAL EXPERIMENTS

## BIOMEDICAL/BIOSCIENCE LABORATORY



- FLIGHT CREW WELL-BEING
- BIOSCIENCE RESEARCH
- SPECIMEN PREPARATION
- FLUID ANALYSIS

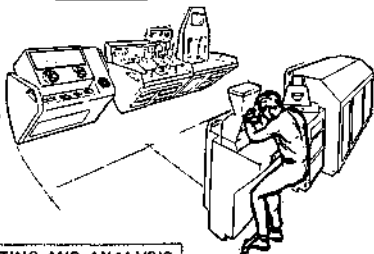
EXPERIMENT AND TEST  
ISOLATION LABORATORY

- ISOLATED EXPERIMENT OPERATIONS
- CHEMISTRY AND PHYSICS EXPERIMENTS
- SCIENTIFIC AIRLOCK
- REMOTE OPERATION

Reproduced from  
best available copy.



## MECHANICAL LABORATORY



- MATERIAL TESTING AND ANALYSIS
- MECHANICAL WORK STATION
- GLOVE BOX

### **Optical Sciences Laboratory**

The optical sciences laboratory is used to service optical equipment and for operations requiring optical support. The laboratory includes equipment and facilities for calibration, measurement, and test activities. It contains a scientific airlock chamber for performance and deployment of experiments. An optically flat, broad-spectrum transmission window is integrated with the airlock chamber; this allows viewing and photography of external experiments and phenomena.

### **Hard-Data Processing Facility**

The hard-data processing facility is used for film storage, handling, and processing, spectral and density calibration, and quick-look film-strip evaluation. The facility services all experiments and operations that utilize film, and is therefore widely used. Film and plate storage under controlled temperature and humidity conditions is available in a facility vault which also is used to shield film to prevent emulsion-fogging by natural radiation.

### **Experiment and Test Isolation Laboratory**

The experiment and test isolation laboratory is a separate compartment within the GPL which can withstand reverse pressure and positive overpressure. Access to vacuum is provided by an airlock chamber, which is an integral part of the facility, and by the total facility itself, which can be sealed and depressurized for extravehicular activity (EVA) or for experiment deployment. The isolation laboratory is used for the experiment and maintenance activities that require isolation from the Space Station environment for safety or other reasons.

### **Electrical/Electronics Laboratory**

The electrical/electronics laboratory provides the instrumentation, test, stimuli generation, controls, and displays necessary for test and calibration functions. As with other GPL laboratories and facilities, the equipment is modularized so that carry-on equipment can be utilized and the laboratory reconfigured. The main service facility is a multi-instrument test console for bench checkout, calibration, and contingency repair. Instruments in the multi-instrument test console can be unplugged and used in remote locations as portable test equipment.

### **Biomedical/Bioscience Laboratory**

The support requirements for bioscience research and monitoring of crew

well-being are combined into a single laboratory due to the similarity of equipment functions. Equipment for bioscience experiments consists of plant, invertebrate, and microbiological-incubation units, plant- and cell-chemistry analysis units, and biological-fluid-handling units. The biomedical equipment will be used to measure heart functions, work performance, and body mass. Biochemistry of body fluids is performed using some of the equipment shared with the bioscience laboratory. Equipment will have the capability of performing automated urine analysis, automated blood analysis, and specimen mass measurement. Routine health monitoring is also accomplished in this portion of the GPL. Biomedical data are displayed here.

### **Experiments/Secondary Control Center**

The experiments/secondary command and control center is a centralized operations center for monitoring and managing the experiment program. This station also provides backup vehicle and subsystem control in the event the crew is forced to evacuate the crew/operations module. Display and control hardware required at the experiment/secondary command and control center is basically the same as that required at the primary command and control center, with additional dedicated experiment displays and controls for monitoring and control of the experiment program. The configuration of the controls/displays allows fully independent two-man operation.

The primary display element is a cathode ray tube (CRT) device. The CRT display is capable of presenting computer-generated data such as characters, vectors, and tabular data, as well as TV imagery and other analog signals. Data from these sources can be shown independently, adjacent to each other, or superimposed one upon another. Color discrimination capability is provided to enhance and highlight particular data. This feature may be used to enhance the visualization of information portrayed.

A programmable function keyboard at each operator's station provides access to the computer. The keyboard-display-computer loop allows the operator to select functions sequentially from a computer-provided "menu." Through a series of fixed-program select keys and a series of function keys, the operator commands the desired operation. This technique allows the operator to implement commands without the need for a dictionary of command codes.

## **Logistics Module**

The logistics module is used to transport cargo to and from orbit. This module is 14 feet in diameter and 28 feet long, and is carried in the cargo bay of the shuttle. Empty weight of the module is 6,638 pounds; maximum cargo capability is therefore 13,362 pounds.

The logistics module supplements the Space Station volume between shuttle flights because it remains attached to the station during that time. It provides for storage of (1) consumables, (2) return cargo (such as wastes and experiment hard copy data), and (3) equipment. The storage volume provided in the logistics module minimizes the storage space required in station modules.

Figure 9 shows the logistics module and indicates the modular cargo accommodation in the pressurized compartment and the transfer concept for large items of cargo. Routine items of cargo are stored in standardized modules which are then moved into the station on demand. Crew members transfer large items of cargo using a cable/brake device temporarily installed for that purpose.

An unpressurized compartment houses propellant ( $N_2H_4$ ) and high-pressure tanks. A two-man EVA airlock is at one end. This airlock also serves as an egress/ingress between the orbiter and the logistics module for routine crew transfer.

The logistics module also may be used for rescue of the six-man crew in an on-orbit emergency situation. This is accomplished by the shuttle transporting a logistics module specially outfitted to support six men for an emergency return mission.

Logistics module subsystems are minimal since the module is supported by the orbiter and Space Station. Structural design of the logistics module is very similar to that of the Space Station modules. Common elements include the neuter docking mechanism, conical sections, and cylindrical pressure shell/meteoroid bumper assembly,

## **SUBSYSTEM DEFINITIONS**

In the selection of subsystems, minimizing initial and total program cost was emphasized as were the following guidelines: (1) applicability of the design for both ISS and GSS, (2) growth to GSS without new development, (3) commonality and modularity, and (4) on-orbit maintenance and replacement.

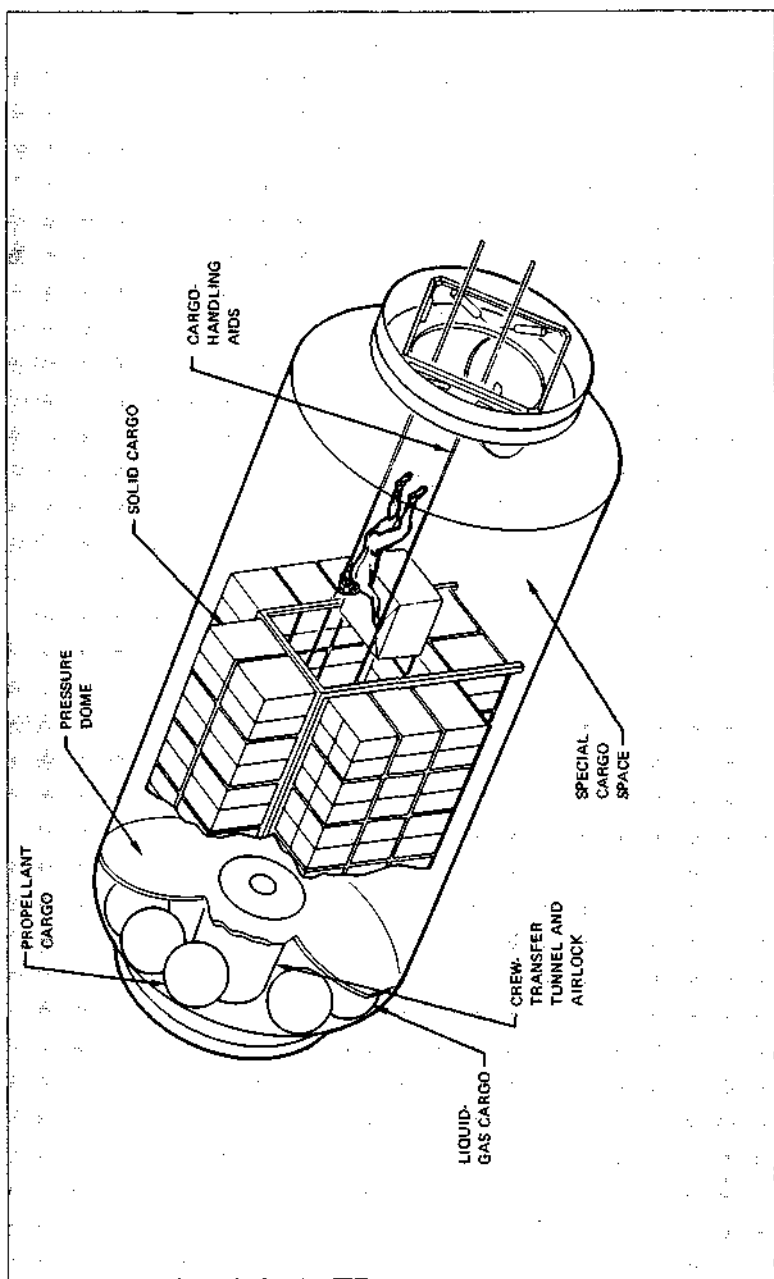


Figure 9. Logistics Module

Subsystem characteristics are summarized in Figure 10 and described in the subsections which follow.

ENVIRONMENTAL CONTROL AND LIFE SUPPORT	COMMUNICATIONS
TWO 6-MAN SYSTEMS PLUS EMERGENCY PACKS	S-BAND TO MODIFIED MANNED SPACE FLIGHT NETWORK
CLOSED WATER	VHF AND $K_u$ -BAND TO RELAY SATELLITE
OPEN OXYGEN	GROWTH SPACE STATION - $K_u$ -BAND TO FREE FLYERS
SOLAR HEAT COLLECTION	
ELECTRICAL POWER	DATA MANAGEMENT
GIMBALLED FOLDOUT ARRAYS	CENTRALIZED MULTIPROCESSORS AND DISTRIBUTED COMPUTERS
TWO-STEP BUILDUP	DATA BUS
16.7 kWe; 31 kWe (GROWTH SPACE STATION)	MULTIPURPOSE DISPLAYS
	FILM
PROPULSION	ONBOARD CHECKOUT
$N_2H_4$ HIGH-THRUST	INTEGRATED WITH DATA MANAGEMENT SYSTEM
$CO_2$ RESISTOJETS	AUTOMATED OPERATION
	FAULT ISOLATION TO LOWEST REPLACEABLE UNIT
GUIDANCE, NAVIGATION, AND CONTROL	STRUCTURAL
CONTROL MOMENT GYROS	EXTERNAL WAFFLE
STELLAR/INERTIAL REFERENCE	BOLT-ON END DOMES
TRIMMED HORIZONTAL ORIENTATION	INTERNAL BIRDCAGE FOR EQUIPMENT SUPPORT
ALL-ATTITUDE CAPABILITY	
MANUAL DOCKING	
GROUND NAVIGATION	

Figure 10. Baseline Subsystems

### Electrical Power

Double-gimbal foldout solar arrays provide electrical power for the Space Station. Each array panel is 5,300 ft<sup>2</sup> in area and produces 16.7 kwh average power. The Lockheed (LMSC) foldout-panel design concept was selected; the concept is still in prototype development, but satisfies Space Station mission requirements and offers a development cost savings. The array consists of two wings, each containing six independent flexible panels. Each panel contains two electrically independent half panels, each of which supplies regulated power to either of the source buses.

The deployment and orientation assembly provides (1) initial array deployment from the stowed position along the power tunnel, (2) continuous two-axis gimbal orientation for maximum solar-energy collection at all station attitudes, (3) individual panel retraction for EVA replacement, and



(4) array retraction for return to Earth of the power/subsystem module by the shuttle. During eclipse periods, the solar panels are feathered for minimum drag and are recycled before the station reenters the sunlight to unwind the trailing cables which transfer power across the gimbal interfaces.

The primary switching assembly in the turret area provides for (1) control of power flow from the 24 half panels to either of the two source buses, (2) control of source-bus connections for either parallel or isolated operation, and (3) control of power flow from the source buses to the four transmission lines. Primary switching is also provided in each station module to (1) sectionalize the transmission lines, (2) control power flow to the main distribution centers from the selected transmission cables, and (3) sectionalize the main distributor buses.

The energy-storage assembly consists of 100-amp-hr, hermetically sealed, temperature-controlled, nickel-cadium batteries located at the main distributor center in each station module. These batteries provide all of the electrical power during eclipses. They also supply (1) supplemental power, (2) emergency power in the event of loss of solar-array power, and (3) primary launch-and-ascent power for the power/subsystems module.

### **Environmental Control and Life Support**

The environmental control and life support (EC/LS) subsystem provides cabin atmosphere control and purification, water and waste management, pressure-suit support, and thermal control for the entire Space Station. Concepts selected for major life-support functions are listed in Table 3.

The cabin atmosphere is maintained at sea-level pressure and two six-man atmosphere-reconditioning subsystems are provided, one in the crew/operations module and one in the GPL.

Metabolic oxygen is resupplied in the form of gas. While an open oxygen loop is used, provisions are included to add oxygen-recovery equipment in the event that state-of-the-art advances make this modification economically attractive. With the open loop oxygen system, the  $\text{CO}_2$  removed from the atmosphere by molecular sieves is used as the propellant for the resistojet low-thrust propulsion subsystem. Should this loop be closed, resistojet propellant would be supplied in the form of excess water obtained from the closed oxygen system.

**Table 3**  
**LIFE SUPPORT ASSEMBLY SELECTIONS**

Function	Selected Concept
O <sub>2</sub> and N <sub>2</sub> storage	Gaseous at 3,000 psia
Atmosphere temperature control	Module heat exchangers
Humidity control	Condenser-separators
Trace-contaminant control	Catalytic oxidation
CO <sub>2</sub> removal	CO <sub>2</sub> molecular sieve
Ventilation	Central fan diffusers
Urine water recovery	Air evaporation
Wash and condensate recovery	Reverse osmosis
Water sterilization	Pasteurization
Fecal collection	Heat plus pumpdown for drying
EVA/IVA	PLSS/PLSS or face mask
Thermal control	Two fluid circuits and integral radiator
Process heat	Solar collection

Full water recovery is provided. A reverse-osmosis assembly purifies 80 percent of the condensate and wash water; the 20-percent residue is cycled to the air-evaporation urine water-recovery assembly. There, the residue, urine, and urine flush water are purified at a 99-percent efficiency.

The total heat generated in the Space Station is rejected through segmented radiators which are structurally integral with the micrometeoroid shield. Each core module contains independent thermal-control loops. A separate water loop between core compartments provides for sharing of the cooling capacity. A solar collector is mounted on the solar-array structure to provide heat for EC/LS processes.

#### **Guidance, Navigation, and Control**

The guidance, navigation, and control (GNC) subsystem provides stabilization, attitude control, navigation, orbit maintenance, and attitude and rate data for experiment support. The subsystem senses, computes, and

receives the commands and data for these functions, while the propulsion subsystem and the control moment gyros (CMG's) generate the actuation forces and torques needed for attitude control. Sensing and computation of station attitude and angular rates are provided within the station. The navigation data are updated by the ground-tracking network, with resultant corrections being accomplished on board the station.

The GNC subsystem provides the Modular Space Station with the capability to maneuver and hold any orientation to support orbit and experiment operations. Normal attitude control is performed by the CMG's, which have sufficient capacity for the worst-case orientation. Any inertial orientation can be held for an indefinite period, subject to propellant expenditure and potential contamination associated with use of the high-thrust subsystem for CMG desaturation.

The primary orientation of the Modular Space Station is trimmed horizontal, which is an Earth-centered orientation. This orientation aligns the Z axis along the radius vector, and the body is rotated about the Z axis so that the bias torque on the vehicle is zero. The amount of rotation depends on the particular configuration of the Space Station.

The GNC subsystem sensors, gyro triads, star sensor, horizon sensor, and star trackers (which provide the all-attitude capability) are located in the power/subsystems module. The star sensor and gyro triads provide the primary trimmed horizontal reference. The horizon sensors are used to provide the acquisition of the Earth-centered reference and a limited-trim or untrimmed horizontal reference.

The low-thrust subsystem receives waste  $\text{CO}_2$  from the EC/LS subsystem and routes the  $\text{CO}_2$  to the power/subsystems module, where it is compressed and stored.  $\text{CO}_2$  is regulated to approximately three atmospheres for distribution to the thrusters, where it is electrically heated and expelled. The requirements for  $\text{CO}_2$  are approximately equal to the EC/LS subsystem output during maximum solar-density years. During low solar-density years, most of the  $\text{CO}_2$  will be expelled nonpropulsively.

#### **Data Management**

The data management subsystem (DMS) provides data acquisition, control, transfer, storage, and processing. Two computer complexes are provided, one in the power/subsystems module for subsystem operations and the

other in the GPL module for experiment operations. Each of the computer complexes is a modular multiprocessor. For backup, the experiment multiprocessor can be rapidly reconfigured to perform the subsystem operation functions.

Data distribution is accomplished by a data bus. The data bus employs a hybrid time-division multiplex (TDM) and frequency-division multiplex (FDM) technique. Control is by a computer input and output controller using standard control words which provide terminal addressing and instructions.

Data acquisition is implemented by analog and digital terminals which have the ability to handle eight standard interfaces. The number of channels in a digital terminal may be expanded to 512 by connecting a remote data acquisition unit (RDAU) to each standard interface. Each RDAU will accept up to 48 (analog or discrete) inputs and will output 16 discrete commands. Analog terminals are used to multiplex nonsampled experiment data onto analog bus subcarriers. The analog bus also carries wideband video on individual subcarriers.

Bulk data storage is by ultrahigh-density magnetic-tape recorders, configured to meet high-data-volume storage requirements and relatively slow access-speed requirements. The storage is used primarily for digital data recording before onboard processing or return to Earth. Magnetic tape recorders also provide for the storage of voice and analog data.

Image-processing equipment is used for selected processing of high-resolution video data, for transforming film data into electronic signals, or for both. Tape storage for experiment video is provided.

A display and control console for subsystem operation is in the crew/operations module. This console is similar to the experiment/secondary command and control console located in the GPL.

### **Communications**

Direct communication with the ground is provided by an S-band transponder which receives voice, commands, and ranging information at a frequency of approximately 2.1 GHz and transmits voice, telemetry, and ranging data at a frequency between 2.2 and 2.3 GHz. An S-band FM exciter and power amplifier, operating at a frequency between 2.2 and 2.3 GHz, is also provided for the transmission of video and digital

experiment data. Two-way voice, low-rate data, and ranging communications with the shuttle are also provided by the same S-band transponder that is used for direct ground communications. However, a power amplifier operating in conjunction with the transponder is required to provide simultaneous voice, data, and ranging information at ranges up to 200 km. A common low-gain S-band antenna system will be used for communications with both the ground and the shuttle.

Communication with the data relay satellite (DRS) is provided by K<sub>u</sub>-band transmitting and receiving systems operating in the 14.4- to 15.35-GHz frequency bands, respectively. An 8-foot-diameter high-gain antenna is used for commercial-quality television or high-rate digital data transmissions through the DRS.

Two-way voice and low-data-rate communications between the Space Station and the DRS are also provided in the VHF band at frequencies from 126 to 130 and 136 to 144 MHz. These links use a low-gain antenna system which will provide nearly omnidirectional coverage.

### **Onboard Checkout**

The onboard checkout (OBCO) system provides checkout and fault-isolation support of subsystems and experiments, as well as limited support of subsystems and experiments in research and applications modules.

The system uses elements of the data management subsystem (data acquisition and distribution, computation, storage, display and control, command generation, and operating-system software).

Local caution and warning units are in each habitable compartment, with overall status provided at both the primary and secondary control centers. Information is distributed among various elements of the system primarily by the digital data bus.

Operation of the OBCO system is largely automatic; the need for crew participation in routine checkout functions is minimal. The system also operates largely autonomous of ground control (although a high degree of ground system interface is possible) because of the system's capability for random access, rapid distribution, and complete control of checkout data. Any or all checkout data points can be selected for transmission to the ground. It is anticipated, however, that ground checkout support will be

limited to assisting the crew in the solution of fault-isolation problems, long-term trend analysis, and detailed failure analyses.

### **Structure/Mechanical**

The pressure shell structure for each of the three modules for the ISS is of the same basic design. Differences exist only in length and radial docking-port cutouts.

A trade study was performed to determine the performance/manufacturing/cost effectiveness of an integrally machined structure versus a monocoque structure. The results indicated that the integrally stiffened structure offered greater benefits in the areas noted because it was significantly lighter, contained fewer individual components and thus was simpler to manufacture, and would cost less than would a similar monocoque structure.

The cylindrical portion of the shell is 160 inches inside diameter and is stiffened with 24 equally spaced integral longitudinal ribs and rings located every 8 inches along the length. Integral end flanges provide a bolted and sealed interface with the conic transition structure. Figure 11 illustrates the shell details for the power/subsystem module. All stiffening ribs are located on the outside surface, leaving the internal surface smooth to facilitate on-orbit repairs. This portion of the shell is fabricated from 2219-T87 alloy in three segments and welded along longitudinal seams. The membrane is 0.060 inch thick and the external stiffeners are 1.0 inch high, measured from the inside surface. The integrally stiffened conic structures are used on all modules to make the transition from the 160-inch diameter to the 102-inch diameter docking interface. This conic configuration is extended on one end of the power module to interface with the solar-array support tunnel. A spherical membrane dome 0.060-inch thick is used only in the power/subsystems module to form an unpressurized compartment to house the propulsion subsystem tanks.

The docking structure is a multipurpose fitting which forms the end closure of the module, provides the structural interface with other modules, provides structural support for the docking mechanism, and forms the frame for the pressure hatch. The fitting is machined from a ring forging of 2219-T87 aluminum alloy. The design allows it to be used for either radial or end docking ports.

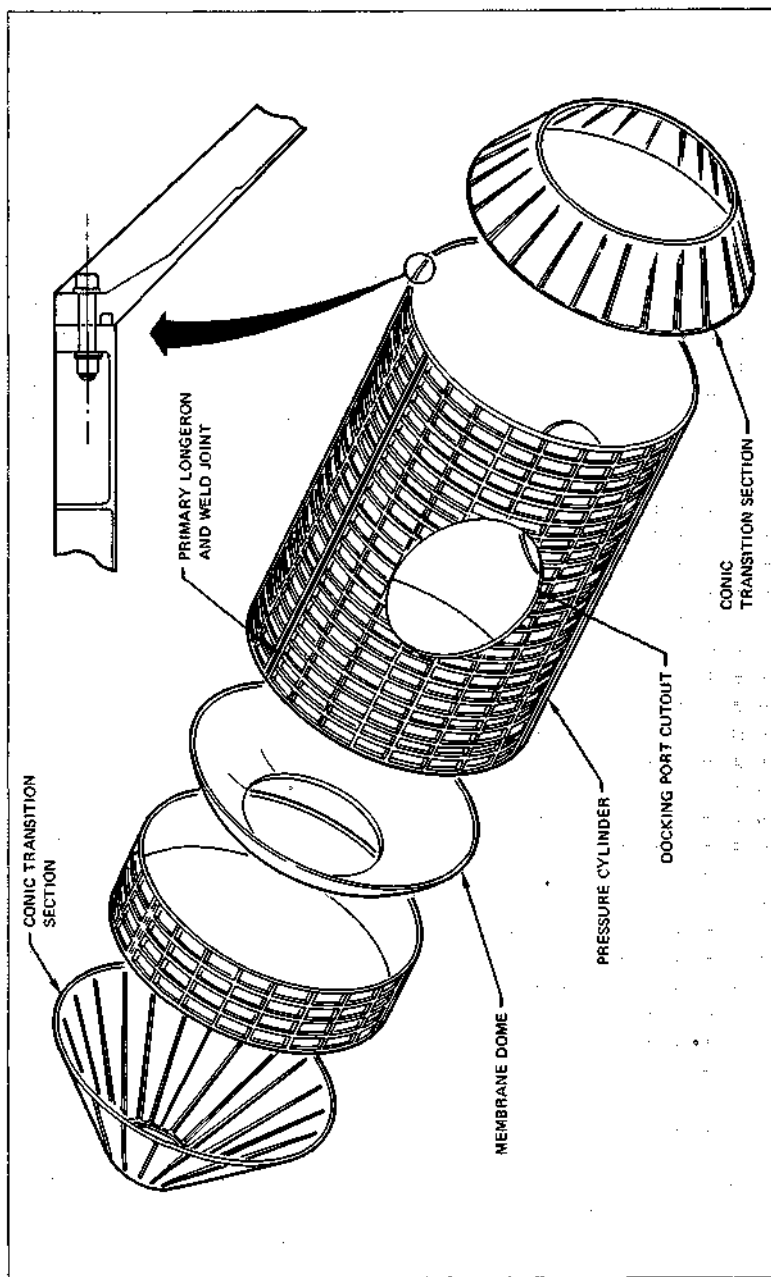


Figure 11. Power/Subsystems Module Pressure Shell

The external shroud encapsulates the pressure shell and provides the radiating surface for the EC/LS subsystem, meteoroid protection, and thermal protection. The 0.016-inch outer surface is formed from extruded sections which contain the flow passages for the EC/LS radiator fluid. A second bumper, to protect the 0.5-inch blanket of high-performance insulation, is attached to the radiator extrusion, forming a box section. The assembly is installed over the pressure shell and supported by fiber-glass insulators. The outside diameter of the radiator is 168 inches.

The internal support structure is a cage-type structure composed of 12 longerons and interconnecting beams spaced at intervals along the longitudinal axis. These beams, connected at the longerons, form a dodecagon shape which fits within the 160-inch diameter pressure shell.

The cage is pinned to the pressure shell at one end of each longeron; thus, longitudinal loads, both tension and compression, are transmitted to the shell through these pins. Radial loads are transmitted to the pressure shell through blocks spaced along each longeron and attached to the pressure shell. The internal support structure provides the mounting for all internal equipment and allows flexibility of arrangement and assembly.

The docking mechanism is of a neuter, clear-center design. The structural interface is 102 inches in diameter, and a clear passage 60 inches in diameter is provided. Each docking interface is the same; therefore, any module may be docked with any other. The mechanism consists of a square frame with guide arms and capture latches mounted in two opposite corners. The frame is supported by eight hydraulic shock absorber/actuators. The displacement of the frame against the force of the actuators absorbs the docking impact energy. After stabilization, the actuators are retracted, the structural latches engaged, and the pressure seal inflated. After two modules are docked, pressurized access to the docking mechanism and structural latches is inherent in the design.

A common hatch design is used throughout the Space Station. All hatches are of domed elliptical sections of aluminum honeycomb sandwich construction, and are capable of withstanding differential pressure in either direction. A dual-seal arrangement is used which consists of an inflatable seal plus a static O-ring seal. Two sizes of hatches are used; most provide 60-inch clearance. Three hatches are smaller and provide 40-inch clearance.



When two modules are docked, the domed hatches provide an intermodule IVA airlock which allows two suited crewmen to gain access to an unpressurized module.

### **LONG-LIFE DESIGN**

The Space Station is designed to allow total maintenance to be performed on orbit. Return of modules to Earth is therefore required only if major damage should be sustained (as from a fire or a docking collision).

The Space Station design provides for all items with limited life to be replaceable. The total number of replaceable items in the system, including limited-life items plus items subject to predominantly random failures, is 3,453. A high percentage of these is in the electrical power subsystem (949) and the EC/LS subsystem (810).

To facilitate maintenance actions, fault isolation is performed to the lowest replaceable unit (LRU). Online maintenance (replacement of the failed item without subsystem shutdown) is used wherever possible, in order to reduce downtime. Subsystems are also designed to be downtime tolerant for maintenance without compromising experiment operations.

The system is designed to minimize maintenance that requires EVA. However, some equipment items that have some risk of failure must be installed on the station outer surfaces. EVA has been found to be the most cost-effective method for repair of these items.

The maintenance work load is expected to be almost evenly divided between corrective maintenance and preventive maintenance, as shown in Figure 12. Failure-prediction estimates indicate an average of 13 failures per month for the ISS configuration. The EC/LS subsystem accounts for the largest portion of these failures. This is due partially to the large number of components that are on continually, and partially to the electromechanical nature of the components. Fans and thermal-control pumping equipment are expected to necessitate the greatest number of maintenance actions in this subsystem.

Preventive maintenance includes all scheduled replacement of hardware items such as limited-life items, and their adjustment and verification after exchange. It does not include housekeeping tasks. Preventive maintenance is expected to require only 30 man-hours per month.

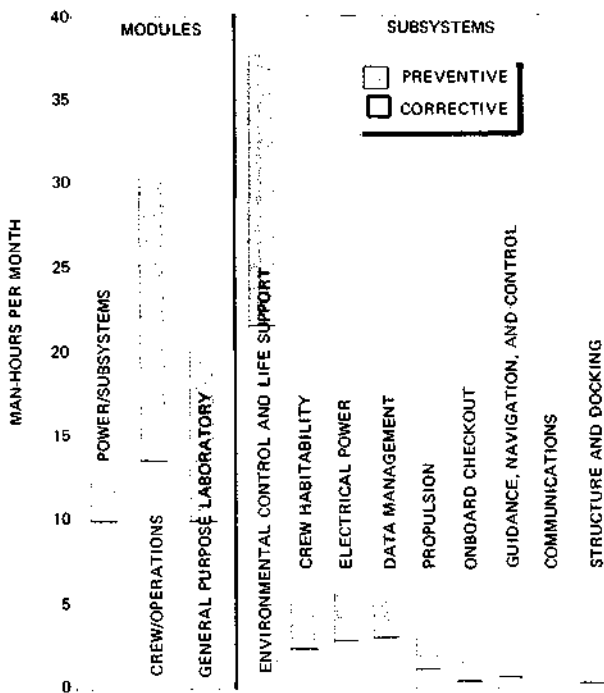


Figure 12. Maintenance Workload (ISS)

The total preventive and corrective maintenance workload is 65 man-hours per month. This figure represents a monthly average for the replacement of the 13 random-failure items and 15 scheduled replacement items out of the total 3,453 line replaceable units.

### SAFETY FEATURES

A high level of safety is achieved using a retreat-refuge (and recovery) approach rather than one of abandonment. First-level backup provisions permit operation with full recovery possibilities if retreat from either of the normal occupancy modules is required. Lower-level alternatives are available by making every module (including RAM's) a safe refuge area for a minimum of 96 hours. If recovery from a contingency is not possible, shuttle rescue is always available as the final backup.

The configuration was optimized from the standpoints of escape paths and rescue potential. Time-distance to a safe area for any crewman is minimized by providing each module with two escape routes that do not terminate in a

common area, and a minimum of 96 hours of life-support capability in each of these areas. Size of hatches permits free passage of IVA- and EVA-suited crewmen, as appropriate.

Failure-tolerant design is one of the most significant safety features of the Space Station; a representative example of the failure-tolerance philosophy is the division of the station into two pressurized, habitable volumes so that any damaged module can be isolated as required. Accessible modules are equipped and provisioned so that the crew can safely continue a degraded mission and take corrective action either to repair or to replace the damaged module. This dual habitable volume division supplemented by emergency life support stores provides three levels of operation for all life-critical functions.

The two primary habitable volumes are the crew/operations and GPL modules. Each is equipped and provisioned so that the six-man crew can remain for an indefinite period in the event the other module becomes uninhabitable. Independent control centers are provided in each module; each provides the capability for command and control of all functions, including fault isolation and detection, caution and warning, and monitoring and control of subsystems.

In a degraded mode in which the GPL module (one of the two dual compartments) is uninhabitable, no additional crew provisions are required to continue the mission until repairs are made. In the event the crew needs to take refuge in the GPL (crew/operations module uninhabitable), the following provisions are available for their support:

- Atmospheric supply and control with the fully independent EC/LS subsystem in the GPL. Accessibility to the normal atmosphere stores in the logistics and power/subsystems modules is provided through redundant interface connections and lines.
- A 30-day contingency supply of water, freeze-dried food, and waste-collection provisions.

In an extreme emergency (such as total power failure), use is made of 96-hour pallets containing a supply of oxygen, lithium hydroxide for CO<sub>2</sub> control, a water boiler for thermal control, food, water, waste collection bags, and a battery power supply. A pallet sized for three men for 96 hours

satisfies emergency requirements best. Two pallets are located in the GPL and one in each RAM and logistics module.

The design of the Space Station provides the capability for a crewman to egress from each module in at least two ways. For example, the crew/operations module is docked to the power/subsystems, GPL, and logistics modules, and a RAM. Each provides a safe refuge, the GPL for an indefinite time, the others for a minimum of 96 hours. Four different escape routes are thus available from the crew/operations module.

---

## Section 2

### EXPERIMENT PROGRAM (ISS/GSS)

---

The definition of a Modular Space Station capable of supporting all Blue Book experiments was a basic objective of the Space Station Study. Seven scientific and engineering disciplines are represented within the Blue Book; i.e., Earth surveys, communications/navigation, life sciences, technology, physics, materials/science, and astronomy. Within each discipline, experiments are grouped into functional program elements (FPE's), groupings that permit the use of common experiment equipment such as cameras, communications, biomedical instruments, etc. An initial study task was the identification of the mode of accommodation for each FPE. Three modes are available: (1) mounted and operated internally within the GPL module; (2) attached to the Space Station in a research and applications module (RAM) and dependent on the Space Station's resources; or (3) housed in a free-flying RAM which operates under the control of the Space Station but is independent of the station's resources. The sections that follow summarize the mode of accommodation selected for each FPE, the schedules for their operation, and the operational techniques to be employed by Space Station personnel in supporting each accommodation mode.

#### EXPERIMENT DEFINITION AND ALLOCATION

Fifty candidate FPE's encompassing the seven disciplines noted above were identified in the Blue Book. Analyses were conducted to determine the most effective mode for their accommodation. Evaluation parameters include these considerations: (1) Does the FPE require an operating mode independent of the Space Station, i.e., altitude or pointing requirements that are incompatible with station operations, and, (2) assuming no incompatibility between station and FPE, what is the relative cost of housing the FPE in a module integral to the station or in a separate, dedicated module. Results of these analyses and the modes of accommodation selected for each of the FPE's are summarized in Table 4.

Table 4  
MODE OF ACCOMMODATION SUMMARY

---

Integral (GPL)	25 FPE's
Physics	
Technology	
Material science	
Attached Modules	17 FPE's
Communication/navigation	
Earth surveys	
Life sciences	
Free Flyers	8 FPE's
Astronomy	

---

These analyses provided the basic requirements for structuring the experiment program including the definition of the number and types of RAM's required, schedules for their operations, the resources required of the Space Station, and program costs.

#### EXPERIMENT SCHEDULES

The two major parameters used in establishing a balanced experiment program schedule were costs (a NASA guideline was minimum cost to initial operating capability) and experiment crew size. The latter point is significant because the Space Station crew size is limited to six men for the first five years of operation (ISS) and increases to twelve for the second five years (GSS). In several instances, notably Earth surveys, there were precursor FPE's which were scheduled early in order that their results might be applied to subsequent FPE's within the same discipline. Using these considerations, a matrix of 20 schedule options was prepared and analyzed. This evaluation resulted in the selection of the experiment schedule illustrated in Figure 13. This schedule presents a reasonable balance among the seven disciplines, the costs to initial operating capability, and the resources required of the Space Station. The matrix analysis also disclosed that the Modular Space Station contained the resources necessary to

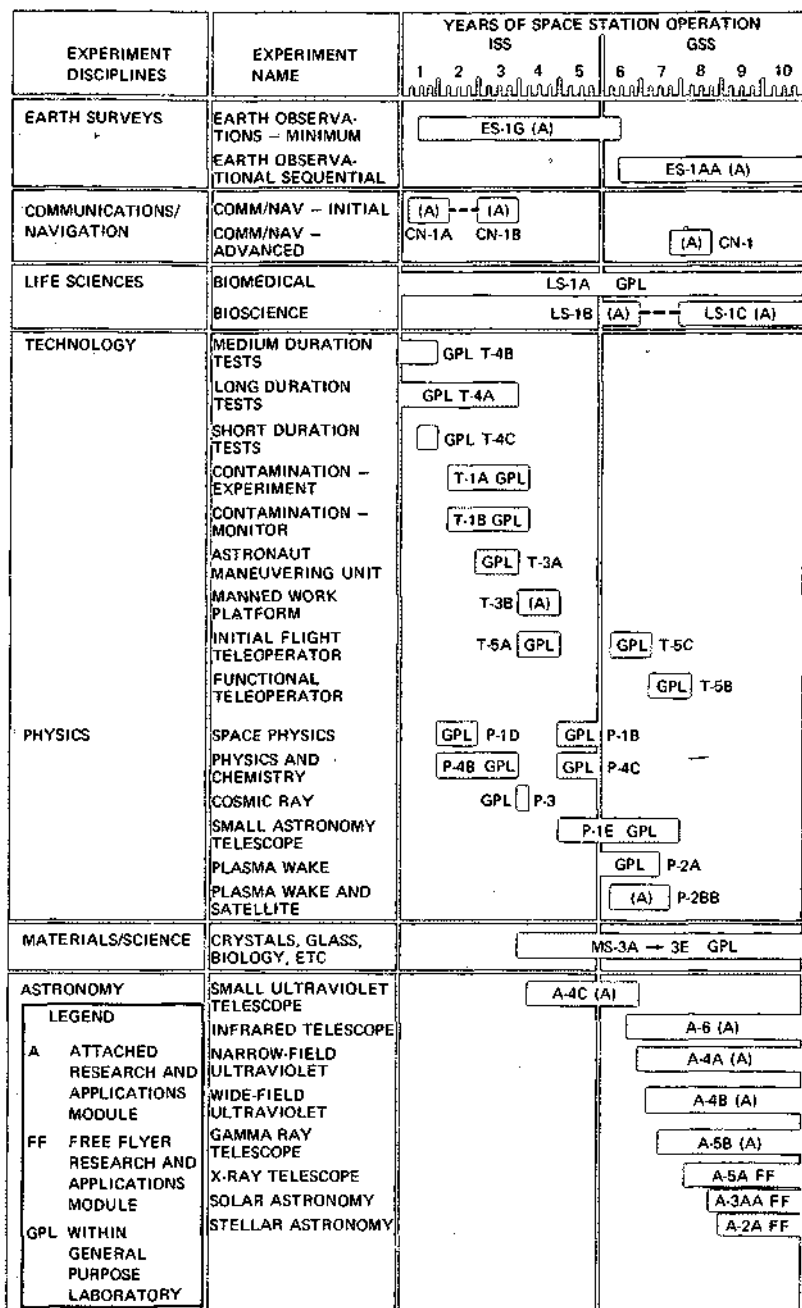


Figure 13. Baseline Research and Applications Program

support a wide variety of experiments and schedules. Thus, while the schedule depicted in the figure was used for program definition purposes, significant deviations could be accommodated without materially affecting the Space Station design or operation. The experiment discipline and name, the mode of accommodation, and schedules are identified. In addition, each FPE subgroup is designated; e.g., LS-IA-Life Sciences, Minimal Medical Research Facility. Table 5 relates these designations to their specific experiment titles.

## **EXPERIMENT OPERATIONS**

The Space Station Program has been designed to accommodate a changing experiment program. During the Initial Space Station phase (first 5 years), one of the six-man crew is responsible for Space Station operations and maintenance, and is designated as the Space Station commander. A second crewman, the experiment officer, is primarily responsible for all experiment operations. The remaining crewmen are assigned to experiment operations and may include principal investigators (PI's). The scientific crew will require a minimum of astronaut training, but will assist as needed in maintaining and operating the subsystems comprising the Space Station. Experiment operations are generally limited to a six-day week, although there are exceptions in instances where the experiment may require continuous observations.

Experiment operations associated with the Space Station were analyzed for the experiment schedule described earlier. This analysis resulted in a set of experiment operating requirements which were in turn applied to the design of the Space Station system and subsystems. Experiment operations were defined for each FPE and its related mode of accommodation. The ISS Program includes both carry-on (integral) and RAM experiments.

The carry-on experiments will be delivered to the Space Station by the logistics module. They will then be transferred to their operating location within the general purpose laboratory. RAM's will be delivered as shuttle payloads. Those that remain attached to the station will be docked to their assigned docking port by the shuttle using a direct docking mode. Attached RAM's, which require manned operation and control of experiments, will have a significant amount of their display and control within the RAM. These data will also be transmitted via the data bus to the Space Station



Table 5

## FINAL FPE/SUBGROUP DESIGNATIONS

1.	A-1	X-ray stellar astronomy	26.	ES-1G	Minimum payload (core)
2.	A-2	Advanced stellar astronomy	27.	CN-1	Communications/navigation facility
3.	A-2A	Intermediate stellar telescope	28.	CN-1A	Communications/navigation Subgroup A
4.	A-3AA	Advanced solar astronomy	29.	CN-1B	Communications/navigation Subgroup B
5.	A-3CC	ATM follow-on	30.	MS-3A	Crystal growth, biological and physical processes
6.	A-4A	0.9-m narrow field UV telescope	31.	MS-3B	Crystal growth from vapor
7.	A-4B	0.3-m wide field UV telescope	32.	MS-3C	Controlled density materials
8.	A-4C	Small UV survey telescope	33.	MS-3D	Liquid and glass processing
9.	A-5A	X-ray telescope	34.	MS-3E	Supercooling and homogeneous nucleation
10.	A-5B	Gamma ray telescope			
11.	A-6	IR telescope			
12.	P-1A	Atmospheric and magneto science	35.	T-1A	Contamination experimental package
13.	P-1B	Cometary physics	36.	T-1B	Contamination monitor package
14.	P-1C	Meteoroid science	37.	T-2A	Long-term cryogenic storage
15.	P-1D	Thick material meteoroid penetration	38.	T-2BB	Short-term cryogenic storage
16.	P-1E	Small astronomy telescopes	39.	T-3A	Astronaut maneuver unit
17.	P-2A	Wake measurements from station and booms	40.	T-3B	Manned work platform
			41.	T-4A	Long-duration system tests
18.	P-2BB	Wake, plasma, wave particle, electron beam	42.	T-4B	Medium-duration tests
			43.	T-4C	Short-duration tests
19.	P-3	Cosmic ray physics laboratory	44.	T-5A	Initial flight teleoperator
20.	P-3C	Plastic/nuclear emulsions	45.	T-5B	Functional teleoperator
21.	P-4A	Airlock and boom experiments	46.	T-5C	Ground control teleoperator
22.	P-4B	Flame, chemistry, and laser experiments	47.	LS-1A	Minimal medical research facility
23.	P-4C	Test chamber experiments	48.	LS-1B	Minimal life science research facility
24.	ES-1	Earth observation facility	49.	LS-1C	Intermediate life science research facility
25.	ES-1AA	Earth observational sequential	50.	LS-1D	Dedicated life science research facility

data management computer for processing, formatting, and any executive actions required. All FPE and RAM engineering and housekeeping data will be monitored and validated by the Space Station onboard checkout system. The experiment computer (located in the GPL) will perform those experiment computations that require a large amount of storage or processing time. RAM's which require atmosphere pumpdown for sensor exposure will utilize the Space Station accumulator capability.

Free-flying RAM's will be docked to the Station for activation and checkout of their subsystems and experiments. This will be accomplished using the Space Station onboard checkout system. When checkout is complete, the RAM will be undocked and transferred to its operational orbit using Space Station tracking, rf control, and RAM propulsion. In its operational orbit, the RAM's guidance and control system will be initialized by rf command to provide the required attitude stabilization, solar panel pointing, and sensor control. Stationkeeping maneuvers will be commanded from the Space Station. Upon completion of the experiment operations, the Space Station will command the RAM to rendezvous and dock for maintenance, data retrieval, and experiment refurbishment/resupply. These operations recycle until the RAM's mission is complete, after which the RAM returns to the Space Station, is docked, and awaits the shuttle's return to Earth.

Table 6 summarizes the resource requirements imposed on the Space Station by the various FPE's and RAM's defined in the schedule described earlier.

Table 6  
SPACE STATION EXPERIMENT RESOURCE SUMMARY

Function	ISS	GSS
Crewmen	4.6	9.5
Power (kw)	4.8	12.1
Data		
Digital (bits per day)	$8 \times 10^{11}$	$8 \times 10^{11}$
TV (minutes per day)	1,320	1,320
Logistics (lb per 90 days)	38,000	29,000
Docking ports	4	8
Steady-state disturbance (g)	$10^{-5}$	$10^{-5}$

---

### **Section 3**

## **OPERATIONS**

---

Continuous on-orbit operation of the Space Station for 10 years presents some unique challenges to current modes of operation which are generally designed to support short-duration missions of a day to a week. For this reason, if true economies in space operations are to be achieved, an integrated mission management philosophy is required in order to avoid duplication of effort and ensure that the station operations can accommodate the needs of a changing experiment program. The mission support operations required to satisfy this integrated mission management concept and the operations associated with the on-orbit buildup and sustained operation of the Modular Space Station are defined in the subsections that follow.

### **MISSION SUPPORT OPERATIONS**

As shown in Figure 14, program operations functions will consist of (1) logistics operations support, (2) mission analysis and planning, (3) flight operations support, and (4) experiment operations support.

Logistics operations support includes inventory management to ensure that required materials and equipment are delivered to the Space Station, and configuration management to ensure that ground personnel will always know the exact orbital configuration, including experiment hardware. Another function of logistics operations is the certification of new equipment, to make sure that it will fit and function properly. All the hardware to be flown with the Space Station is subject to station interface control.

Mission analysis and planning is accomplished at two levels. The first level is a 10-year plan which generally structures the total mission. This plan is in 90-day segments, each of which, for planning purposes, will be considered as a separate mission. The second level is each 90-day plan which establishes the objectives for that mission and the activities necessary to accomplish these objectives. The on-orbit crew will have a high degree of autonomy and will be working to this mission plan, not predetermined timelines. The

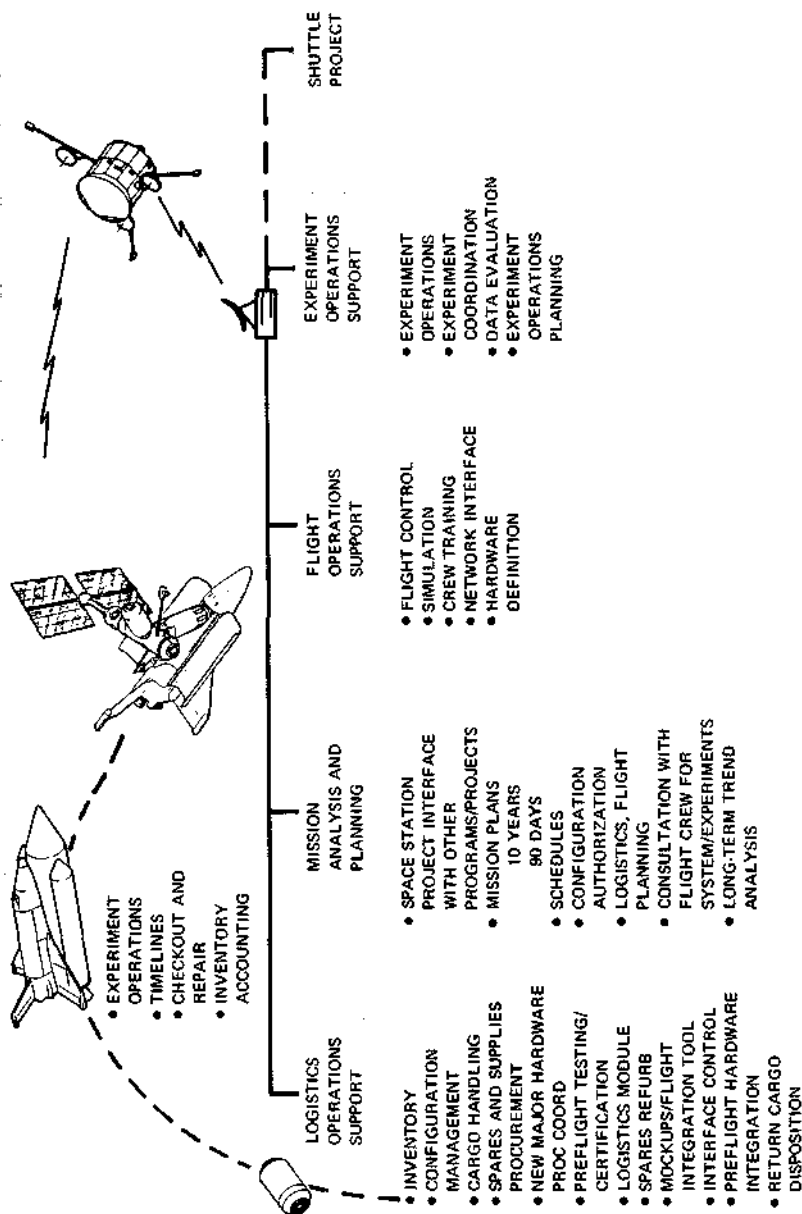


Figure 14. Space Station Mission Management Operational Functions

mission plan will provide crew members with general requirements for the conduct of the mission, from which they will develop their own timelines every 24 to 48 hours.

Flight operations support will assist in onboard status monitoring and fault isolation and analysis. It also will coordinate all systems status and trend data for crew training, simulation, and other activities associated with preparation for flight operations.

The prime function of experiment operations support is to assist in planning experiments, establish their procedures, and provide the capability for principal investigators to participate (on the ground) in real-time activities of their experiment while it is in orbit.

In the performance of mission management operations, the flight integration tool (FIT) from the development program is utilized. Table 7 indicates the mission support functions in which the FIT is used.

Table 7  
MISSION SUPPORT FUNCTIONS FOR THE  
FLIGHT INTEGRATION TOOL

---

Aid configuration control of the orbiting Space Station.

Aid troubleshooting of orbital problems.

Achieve functional and physical integration of new or modified Space Station flight hardware, experiments, and experiment modules.

Achieve functional integration of new or modified software.

Aid flight-crew proficiency training.

Verify the Space Station-flight control center functional interface.

Aid in development and revision of maintenance plans and procedures.

Aid principal investigator orientation.

Qualification-test software.

Indoctrinate the scientific community.

---

## **FLIGHT OPERATIONS**

The Space Station orbit envelope specified by NASA has an altitude between 240 and 270 nmi at an inclination of 55 degrees; the baseline orbit altitude is 246 nmi. The latter is an average altitude; it corresponds to an altitude of 242 nmi at the equatorial crossing.

The Space Station experiment program can be accommodated within the specified envelope of 240 to 270 nmi altitude at a 55-degree inclination. Requirements of Earth-survey activities dictate the specific orbit selection since a satisfactory orbit for these activities is acceptable to other disciplines, and Earth surveys are most affected by orbit selection.

A 246-nmi altitude was established based on mapping rates and daily ground-track separation distance (approximately 200 nmi, measured at the equator where the greatest separation of ground tracks exists).

Buildup and activation, sustained operations, and logistics support are described below.

### **Buildup and Activation**

The buildup phase of the ISS mission covers the first 60 days (three launches). During this phase, two assembly crewmen accompany each of the Space Station modules to orbit as passengers in the Space Shuttle. These assembly crewmen perform the interface mating, checkout, and operation functions on the Space Station while the Space Shuttle remains attached to the station configuration. These crewmen depend upon the shuttle for life support and living accommodations while working in the Space Station module(s). The shuttle acts as the on-orbit support facility during buildup.

The power/subsystems module is launched to orbit first. It is equipped with an EC/LS subsystem and one set of batteries which provides electrical power until solar-array deployment and checkout, which is the first activation operation. Once the on-orbit crew and ground support personnel have established the module's readiness for 60 days of unmanned operations, the power/subsystems module will be configured for unmanned operations.

The second module to be launched is the crew/operations module. It is directly docked to the power module by the Space Shuttle. Aids are provided on the Space Station to assist the orbiter pilot in the performance

of manual docking (see Figure 15). A T-bar is located above the target-docking hatch, and, when viewed through the Space Shuttle docking telescope, its image yields information relative to lateral and vertical displacement of the Space Shuttle. In addition, target-image diameter calibrations provide data relative to distance to the docking interface. The T-bar and target circle are both electroluminescent.

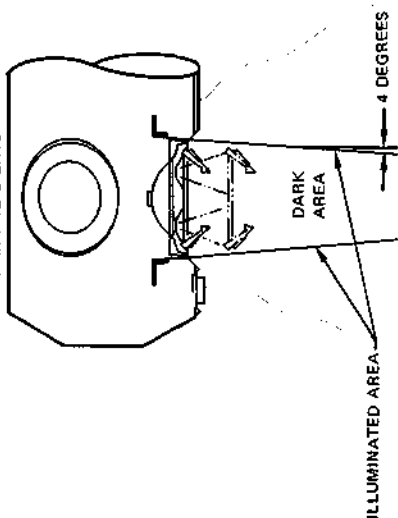
To ensure collision avoidance, a lighting system provides a positive cue to the pilot should the shuttle inadvertently maneuver to a potential collision position.

Immediately following docking, the Space Station attitude control is deactivated and the attitude of the orbiting configuration controlled by the Space Shuttle.

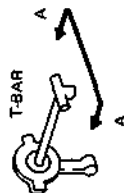
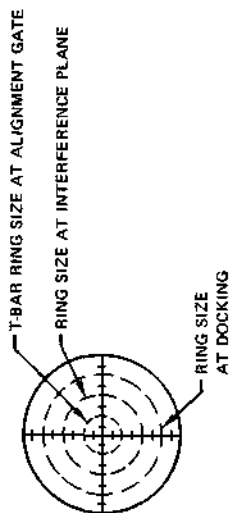
The crewmen enter the crew/operations module and mate the interface connectors. Until the electrical power interfaces are mated and checked out, the crew/operations module is dependent on the Space Shuttle for electrical power. Operations analyses were performed and timelines prepared to assure that operations required for orbital assembly and checkout of the Space Station could be accomplished within the time available while the Shuttle was on orbit. Results clearly indicated that all assembly and activation functions could be accomplished on any given mission in less than half of the time available, thus providing ample time for contingencies. Table 8 is a typical sequence illustrating the time required for interface connections between the power/subsystems module and the crew/operations module. Once the atmosphere interfaces are mated and the module is on Space Station power, the crew will activate the environmental control system and verify proper operation.

The third and final flight of the buildup operations is delivery and mating of the GPL to the crew/operations module. The crew will transfer to the GPL, activate its systems, perform the required interface-mating operations, and perform subsystem operations and checkout to verify the operational readiness of the configuration.

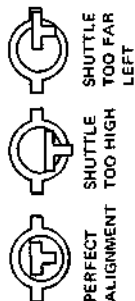
COLLISION CORRIDOR  
WARNING LIGHTS



DOCKING TELESCOPE



VIEW A-A



SHUTTLE YAWED RIGHT



T-BAR RING AND OUTSIDE  
RETICLE CIRCLE CONGRUENT AT DOCK

Figure 15. Docking Aids



Table 8  
POWER/CREW MODULE DETAIL INTERFACE ESTIMATES

Connection	Number	Hookup Time (min)	Checkout Time (min)	Total Time (min)
Air ducts	2	42	6	48
Atmosphere supply	4	64	12	76
Power (VDC)	4	70	20	90
Caution and warning	2	42	20	62
H <sub>2</sub> O thermal	4	24	20	44
Atmosphere pumpdown	4	24	12	36
Propulsion (N <sub>2</sub> H <sub>4</sub> )	4	72	40	112
Propulsion (GN <sub>2</sub> , CO <sub>2</sub> )	4	24	12	36
Data bus	4	24	40	64
Power (VAC)	2	10	20	30
Thruster control	2	18	20	38
Total Time = 636 man-minutes				

The activation phase of the Space Station mission includes the first three logistics-module launches. During this phase, certain equipment, which was off-loaded from the Space Station modules to meet the 20,000 pound Space Shuttle launch limit, will be delivered to orbit on the logistics flights for installation in the Space Station.

The crewmen enter the logistics module and mate the interfaces between it and the crew/operations module. Once the interface operations have been completed, the crew begins transfer of equipment off-loaded from the Space Station modules (typical of this equipment are control moment gyros and batteries). Following the transfer and installation of the off-loaded items, the newly installed equipment is checked out and its operability verified.

#### Sustained Operations

Crew tasks required for housekeeping and maintenance activities have been minimized to provide the maximum possible number of man-hours on-orbit for experiment operations; routine station operations (e.g., subsystem

operation, switching to backup systems) are largely automated. One crewman (Space Station commander) is assigned the responsibility for Space Station operations and maintenance. A second crewman, the experiment officer, is primarily responsible for all experiment operations and partially responsible for Space Station operations. The four remaining crewmen are assigned to experiment operations. Principal investigators may be included in the group of four experiment operations personnel. The scientific crew will require a minimum of astronaut training; i.e., only that related to safety, emergency procedures, and personal tasks (hygiene, etc.).

The duration of crew overlap when crews are being rotated is nominally planned for 12 hours, though this period could be reduced or extended.

The Space Station subsystems have been designed to provide the capability for single- or dual-shift operations on-orbit. Evaluation of workloads, power requirements, equipment loading, and experiment targets indicated that a two-shift duty cycle is preferable. This two-shift cycle would comprise two 12-hour tours of responsibility, with each crewman performing 10 hours of work. That is, 12 hours of responsibility would be assigned to one-half the crew, with freedom to perform the assigned hours of duty and other individual tasks while remaining available to respond to any contingency. There would be six tours of duty and seven tours of responsibility for each crewman during the week.

### **Logistics Operations**

Logistics operations provide for transportation of cargo to and from the Space Station, rotation of Space Station crews, and rescue of the entire crew in an on-orbit emergency situation. In the selected ISS logistics system concept, crews are transported in the crew compartment of the Space Shuttle orbiter vehicle, while cargo is transported in a logistics module housed in the orbiter cargo bay. Crew rescue is accomplished by the shuttle with a logistics module specially outfitted to house and support six men for an emergency return.

Transporting crews in the orbiter is preferable to transporting crews in a crew/cargo module (CCM) because development costs are lower. Note that while the logistics module is designed to accommodate six men for rescue, substantial additional cost (\$71M) is required to develop and produce

crew/cargo modules because they must support crews during both ascent and descent missions and in routine operations.

Since minimum initial cost to initial operating capability (IOC) is the overriding study guideline, the selected approach for planning and costing purposes is to rotate Space Station crews two at a time in the shuttle, with flights every 30 days. The design of the Space Station however does not preclude the utilization of a crew/cargo module (which would reduce the frequency of shuttle flights), and this approach could be readily implemented.

CCM's will be required for rotation of GSS crews. Crew rotation requires six men at a time, and therefore the CCM is sized to accommodate six men and cargo (twelve crewmen may be accommodated for emergency rescue).

The logistics module is docked to the Space Station by the orbiter and remains attached between shuttle flights. Supplies are transported to the Space Station from the logistics module as needed. The majority of solid cargo items can be safely handled and transferred by the crew without the aid of a cargo-handling system. However, some items exceed the capability of a crewman to safely control without the assistance of a mechanical aid. One such device uses a cable system and cable tracker. The trackers and guide cables constrain the cargo items while the crewman provides the force to translate the item.

**Section 4**  
**PROGRAM DESCRIPTION**

---

The objective of the Modular Space Station study was the definition of a low-cost, manned, Earth-orbiting program capable of accommodating a variety of research and applications experiments. The Space Station element would be capable of sustained operations for a period of at least 10 years, and modularized to permit growth.

The resulting Modular Space Station Program evolved from a set of Level I Guidelines established by NASA and a set of representative experiments defined by the Reference Earth Orbital Research and Applications Investigations (Blue Book). Guidelines that were influential in the definition of the Modular Space Station Program and the selection of the modular design concepts are summarized below:

- Definition of a modular Space Station concept permitting the attainment of a six-man Initial Space Station (ISS) capability with growth to a twelve-man Growth Space Station (GSS).
- Total cost of the program is a primary consideration with emphasis on minimum cost to IOC.
- Commonality is a primary consideration, with a goal of maximizing commonality between structures, systems, and subsystems for all program elements.
- Maximum shuttle launch frequency of one per month for Space Station support.
- The development approach will provide the basis for reducing the number and cost of test articles.
- "Design to" weight of a shuttle transported module shall not exceed 20,000 pounds.
- Maximum external module dimensions of 14 feet in diameter by 58 feet in length.
- Phase C go-ahead in FY 1976.
- Initial Space Station will utilize subsystems and components that minimize development costs prior to IOC.

The sections that follow summarize the program that evolved, including the schedules, specifications, plans, and costs that permit the attainment of the objective and requirements summarized above.

### **Program Schedule**

The master schedule depicted in Figure 16 was developed for the Modular Space Station Program assuming a FY 1976 authorization to proceed. This schedule illustrates the phased relationships between the ISS and GSS and portrays the number of shuttle launches required for support of the Space Station and the experiment program (described in Section 2). Note that the design, development, test, and operations phases for both ISS and GSS have been timed. Program features of frequent resupply, maintainability, and onboard fault isolation make possible new concepts of program development, resulting in high confidence with limited test activities. The development program includes verification to prove technical performance and establish confidence that an orbital facility, safe for personnel and capable of supporting a 10-year program, has been delivered on orbit.

Some of the more important aspects of the development and test program are:

- A single CEI specification governs the design of all modules, with final assembly, test, and integration achieved by a single contractor at one facility.
- Imposed environmental testing, both development and qualification, is concentrated at the assembly hardware level and lower; it is not performed at the systems (module) level.
- Testing of assembled modules and/or assembled clusters is limited to design development tests using a functional model, design qualification demonstrations utilizing a FIT, and acceptance tests of flight modules.

Implicit in this test philosophy is the intent to eliminate environmental, mission-profile qualification testing at the module level or above, and to minimize repetition of integrated systems tests, whether performed at the factory or at the launch site.

The functional model (FM) shown in Figure 17 is used as a breadboard for development of electrical/electronic/data systems and module-to-module electrical interfaces. The FIT modules are developed in parallel, using

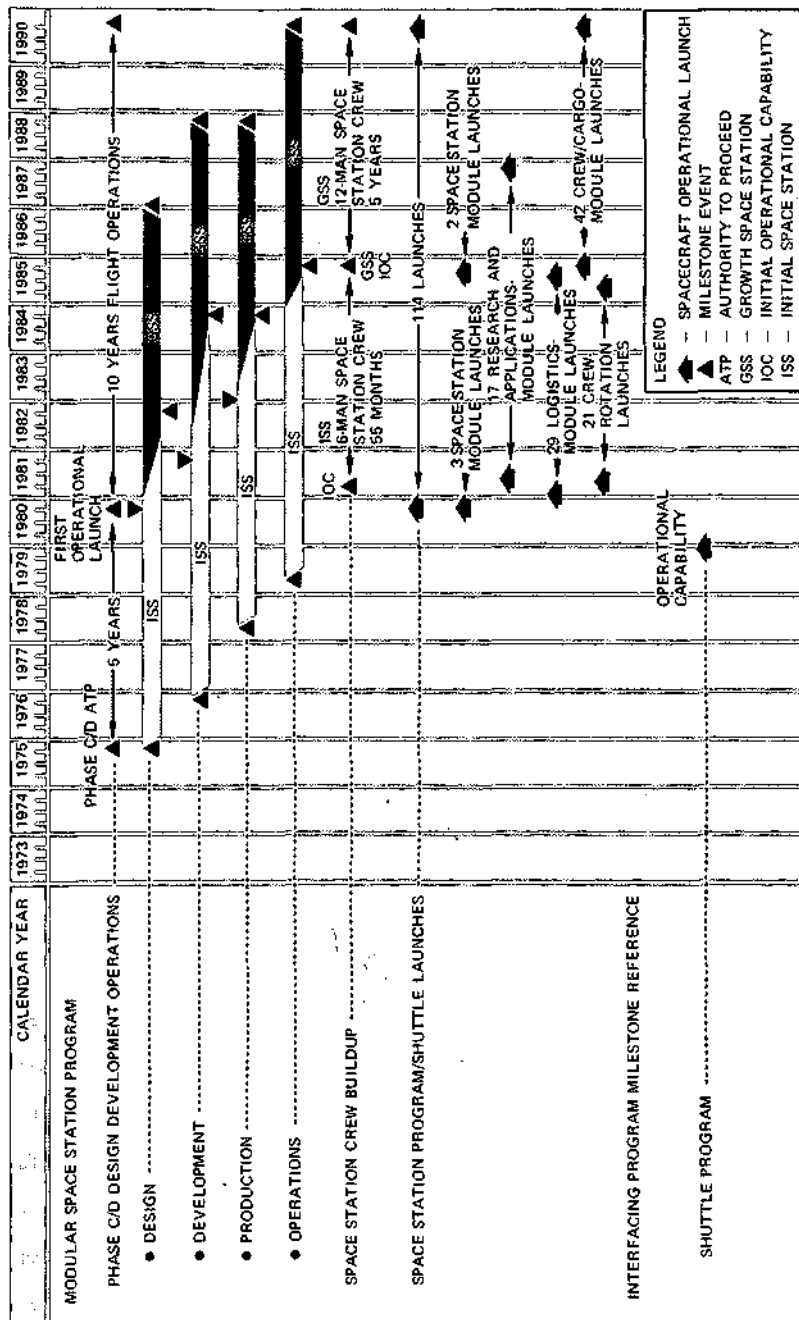
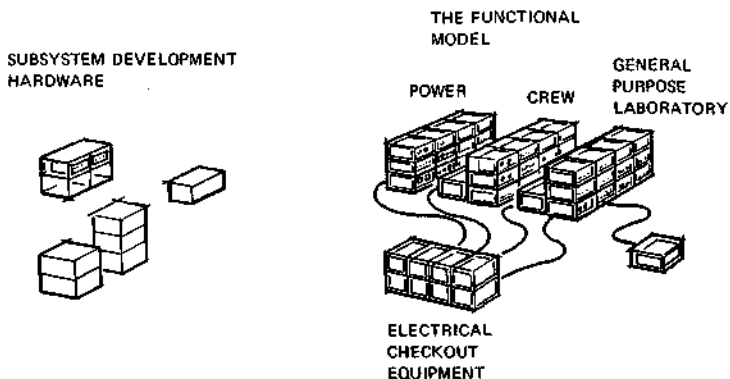


Figure 16. Modular Space Station Program

(FUNCTIONAL MODEL)

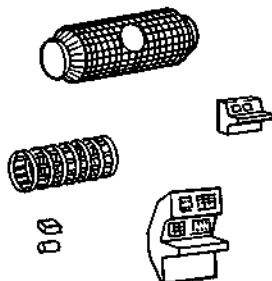
- INTEGRATE ELECTRIC/ELECTRONIC EQUIPMENT
- DEVELOP ONBOARD CHECKOUT GUIDANCE AND NAVIGATION, ETC. COMPUTER PROGRAMS
- DEVELOP ELECTRICAL CHECKOUT EQUIPMENT



(FLIGHT INTEGRATION TOOL)

- INTEGRATED HARDWARE AND SOFTWARE TESTS
- VERIFY PROCEDURES
- FLIGHT MODULE ACCEPTANCE TESTS

**QUALIFICATION TEST HARDWARE**



- TRAINING
- TROUBLESHOOTING
- NEW EQUIPMENT OR MODULE ACCEPTANCE TESTS

**FLIGHT INTEGRATION TOOL**

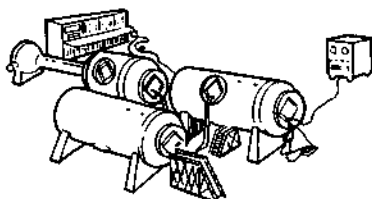


Figure 17. Space Station Functional Model and Flight Integration Tool

refurbished test specimens from the qualification-test program. The FIT modules are used as production prototypes to develop cable and wire runs, assembly techniques, etc. Each of the FIT modules will be tested, using production GSE, after which it will be substituted for its counterpart in the FM. After all three have been checked out against the FM, they will be assembled into an ISS configuration, and will serve as a verification tool for the flight articles.

The production flight articles will be manufactured next (Figure 18). They will be substituted for the FIT modules, one by one, and their operations verified. The flight articles then will be assembled into the ISS configuration. The interchange of modules between the two verifies the intermodule interface and overall operation of the flight articles and the FIT, the latter of which will support the 10-year program on the ground for integration of subsequent changes and/or new hardware. After this integrated test, which must verify readiness for orbital operations, the modules will be disassembled, the items to be offloaded removed, and the modules shipped to the shuttle launch site for loading in the orbiter and for subsequent launch. This process is illustrated in Figure 19.

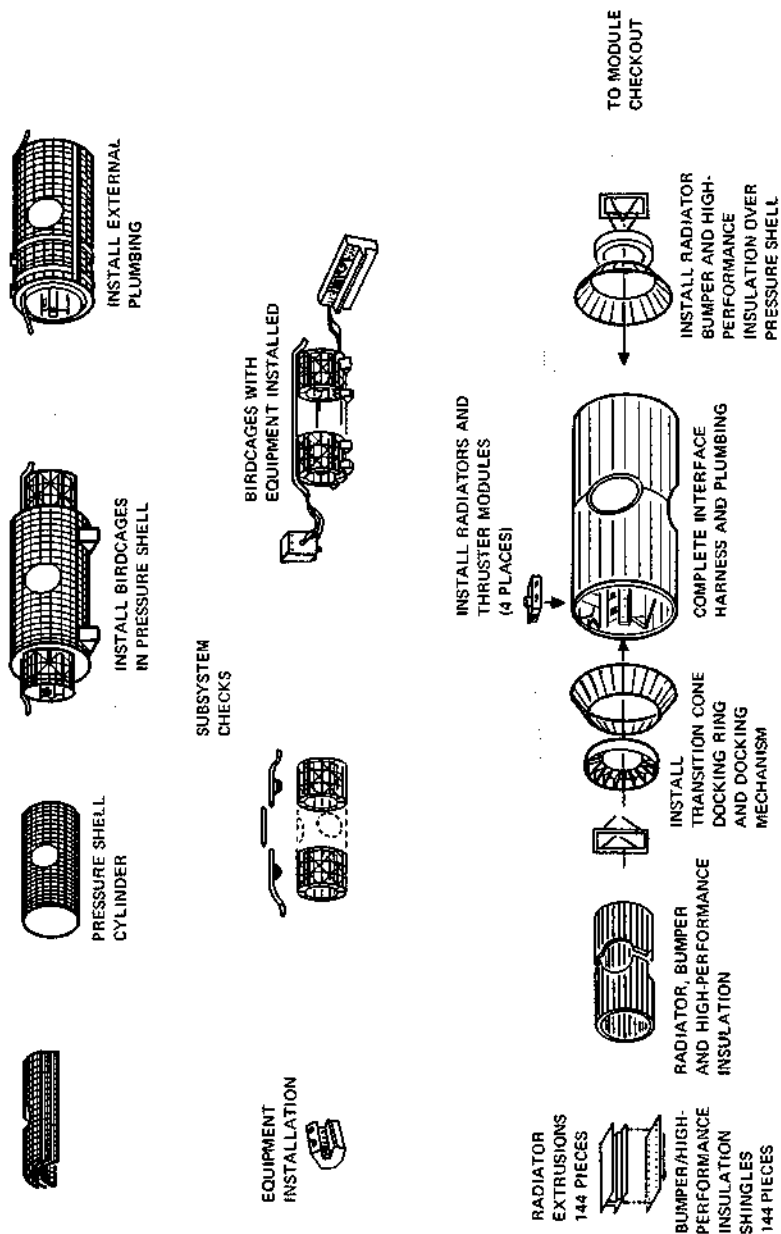
Modules are orbit-ready when shipped from the factory. Should any launch-site testing be required, it will be confined to tests no more rigorous than the acceptance testing performed at the factory. Major disassembly and tests at lower levels of assembly will not be permitted in the field, except when necessary to isolate malfunctions.

Following completion of the Space Station development, the FIT is to be located at a site that most conveniently accommodates the majority of its continuing activities.

## **SPECIFICATIONS AND PLANS**

Data necessary for the initiation of the Modular Space Station Program Phase C/D have been prepared and documented in a series of specifications and plans that have been reviewed and approved by NASA/MSFC. Using the Level I Guidelines provided by NASA as a base, and augmenting these with requirements resulting from performance/operations/design/cost trade





**Figure 18. Flight Module Manufacturing Operations**

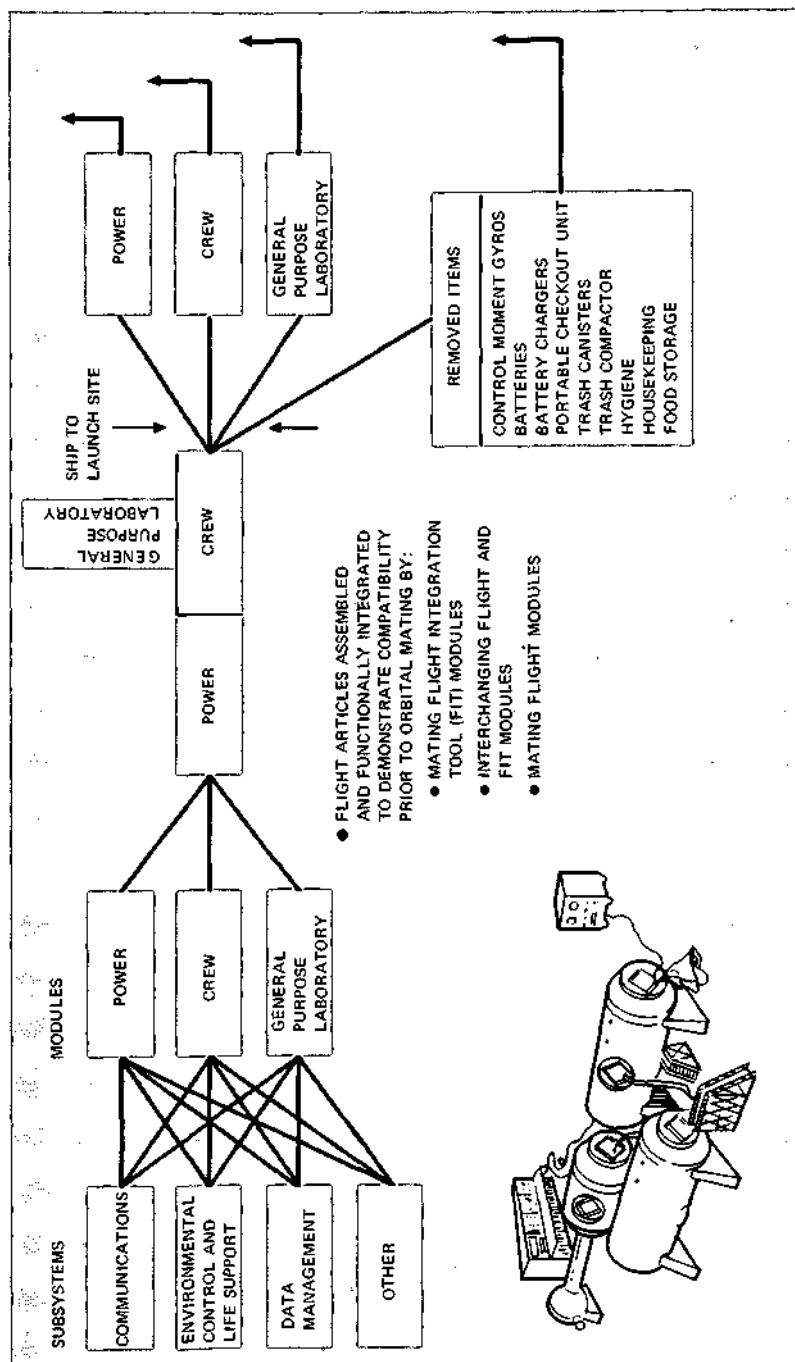


Figure 19. Modular Space Station ISS Hardware Flow (Ground)

studies conducted during the course of the study, the following specifications were prepared:

- Program Specification                      Space Station Program (Modular)
- Project Specification                      Modular Space Station Project
- End Item Specifications                      Initial Space Station Modules  
    Logistics Modules  
    Ground Support Equipment  
    Facilities
- Interface and Support Requirements

These specifications are highlighted on the specification tree (Figure 20) and are documented in MSFC-DPD-235, CM-01 through -04. The techniques used in evolving the performance/design/operational requirements for the program, project, and constituent systems (end items) were also developed to provide requirement traceability. If the program is to be cost effective, it should be possible to trace any design or operating solution back to one or

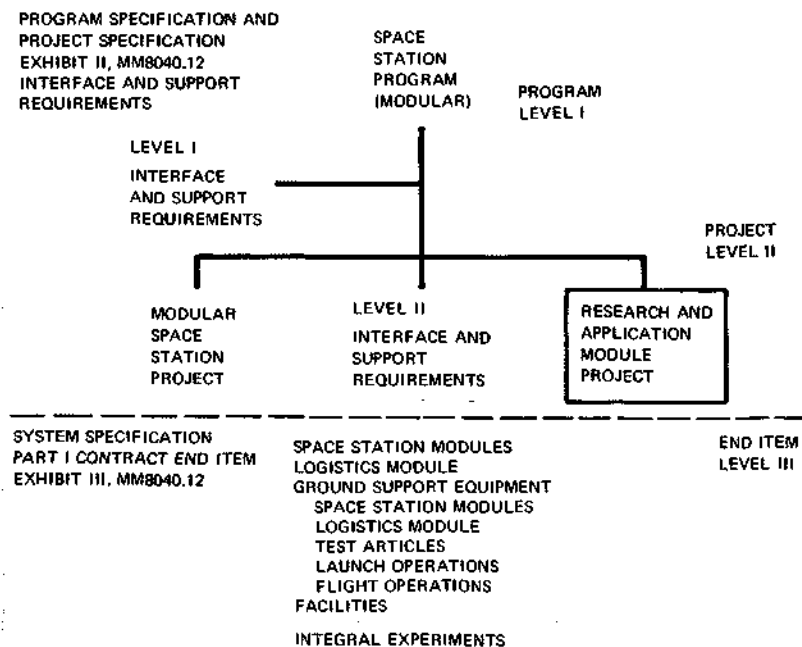


Figure 20. Space Station Program (Modular) Specification Tree (Phase B)

more parent requirements that exist at the program and project level. This traceability is an important aspect in assuring design responsiveness, and in quantifying the costs related to specific requirements.

A program plan was prepared defining the master plan for the development and operation of the Modular Space Station Program. This plan was complemented with a series of 16 project plans. These plans encompass the areas of design, manufacturing, test, and operations for all of the elements comprising the Space Station Project.

## **PROGRAM COSTS**

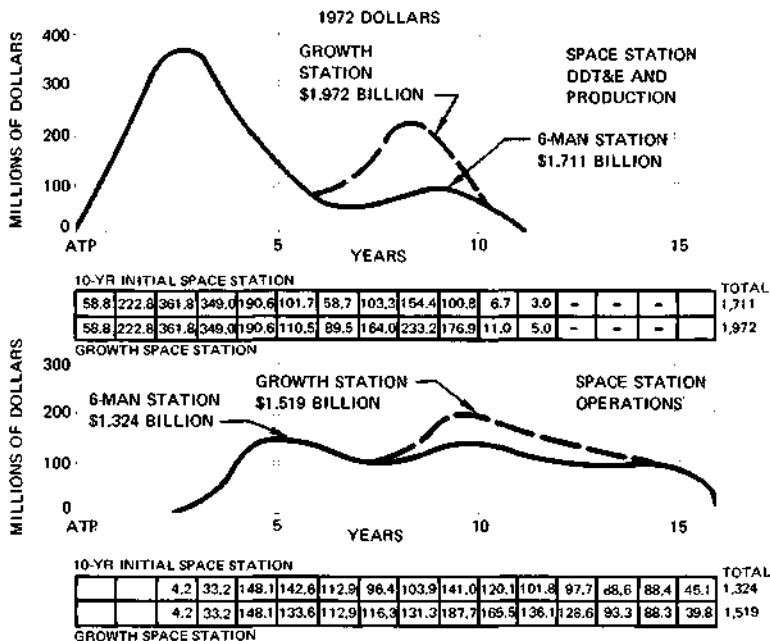
The Space Station Program consists of a 5-year development period and an extended operational period, with provisions for growth during the period. For study purposes, the operational period is 10 years and a growth step occurs 5 years after the start of on-orbit operations. The growth step consists of adding two modules to the basic component of three to increase the crew capability from six to twelve men.

The representative experiment program includes production of 14 research and applications modules (RAM's) during the 10-year program. The 14 modules consist of 3 free-flyers and 11 attached modules (3 early RAM's are refurbished and reused, resulting in a total of 17 launches). Orbital stay times vary for each module; the maximum simultaneous on-orbit complement is nine modules.

Figure 21 shows funding requirements for DDT&E and production (upper curve) and operations, including shuttle launches (lower curve) for two programs. The GSS program is depicted by the dashed line, and the funding required for support of a 10-year, six-man station is illustrated with the solid line.

The DDT&E and production-funding requirements for the station associated with either program are identical for the period up to IOC. Divergence of the two curves thereafter results primarily from the difference in the number of Space Station modules required. In the growth program, two station modules, two crew/cargo modules, and their initial spares are added, while the six-man station requires the addition of only one more module (power) for the second 5 years of operation.

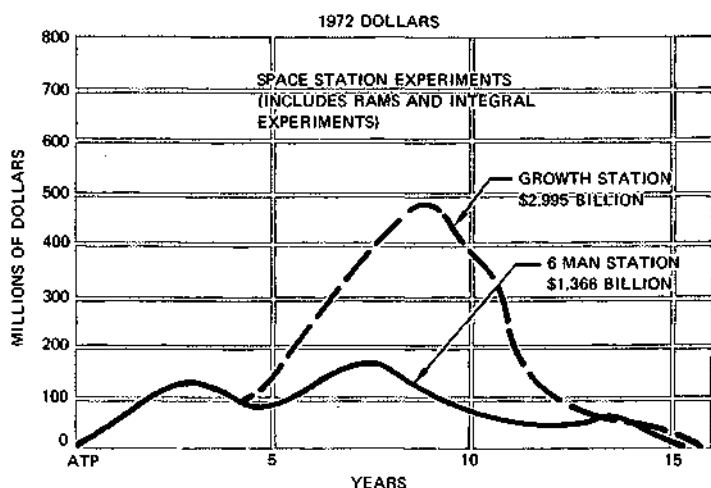
The operations funding requirements for the two programs include the costs for operating the station on-orbit plus the costs for operational spares. Again,



**Figure 21. Modular Space Station Funding Comparison  
(DDT&E, Production, and Operations)**

the two programs are identical during the years preceding IOC. About \$200 million of these costs are for the subsystem spares required for the first 5 years of operation. The increase in funding requirements that occurs about the 10th year after ATP is a result of the procurement of spares necessary for the following 5 years of operation. Deferral in procurement of these spares was deliberate, since NASA can take advantage of the first few years of operational experience in order to more effectively define the types and quantities of replacement items required. The difference in the shape of the second "hump" for the two programs results basically from the different number of station modules flown.

Figure 22 depicts the funding requirements for the experiments to be accomplished during the Space Station Program. Included are the costs for developing, integrating, operating, and maintaining the experiments and their associated GSE for the life of the program. These costs also include the development, fabrication, and operation of the RAM's and the integration of both RAM and integral experiments into their respective modules.



10-YR INITIAL SPACE STATION															TOTAL	
36.0	72.0	102.0	104.0	98.9	122.8	171.0	180.7	143.2	85.6	54.5	51.3	33.3	90.2	20.1	—	1,366
35.1	64.8	97.3	99.2	98.6	215.8	283.8	410.9	480.5	431.8	395.9	146.5	93.0	73.0	68.0	1.5	2,995
GROWTH SPACE STATION																

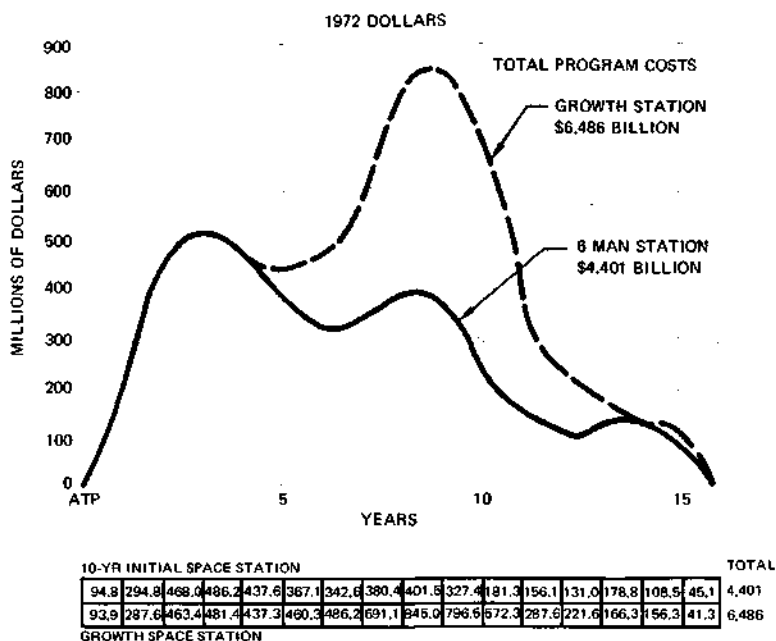
**Figure 22. Modular Space Station Funding Comparison**

The six-man station program, whose experiments are predominantly integral experiments, includes the use of five attached modules. The growth program includes 14 attached modules and three free-flyers.

Major differences between the two programs are concentrated in the astronomy and life-sciences disciplines. The experiments in the remaining five disciplines (Earth surveys, material sciences, communication/navigation, technology, and physics) are essentially the same for both programs.

The six-man program was intentionally constrained to represent a typical minimum cost example while the growth program was constrained only by physical resources existing within the twelve-man station in regard to the experiments to be accomplished. Thus, the two represent minimum and maximum funding requirements.

Figure 23 depicts the total funding required for the growth program (dotted curve) and for the 10-year, six-man station (solid curve). These curves represent minimum and maximum experiment utilization of the facility as discussed above.



**Figure 23. Modular Space Station Funding Comparison (Total Program Costs)**

Of the total expended in the six-man program, approximately 30 percent is for experiment development and integration, 10 percent for shuttle launches, and 60 percent for development and operation of the six-man Space Station and its support of the attendant experiment program.

---

## Section 5

### RESEARCH IMPLICATIONS

---

Guidelines for this study emphasized that existing technology be used wherever possible in the Space Station design. These guidelines were established in order to assure that development costs for the Space Station would be held to a minimum. As a result, the Space Station design does not require major technological advances.

Certain technical areas do, however, warrant supporting research and technology effort. The majority of these are in the category of advanced development; i.e., development of items whose lead times extend beyond the period normally allowed for Phase C (Design). MDAC has cost-optimized the Space Station Development Phase (ATP to first launch) at five years. Review of the development required in each of the subsystem areas disclosed approximately 70 elements of the selected system/subsystem concepts whose development should be started before initiation of Phase C. A number of these are listed in Table 9, together with their associated SRT technology panel. Details of the time required for advanced development and the accompanying costs for each item are presented in MSFC-DPD-235, SE-10, Supporting Research and Technology.



Table 9  
ADVANCED DEVELOPMENT SRT ITEMS

SRT Title	Technology Panel
Array orientation/drive system	P
Power management by computer	P
Power regulation system evaluation	P
High-level power transfer and connector development	P
Body composition and fluid balance methodology	B-Res
Potable water monitoring and contamination control	B-Res
Biological specimen container	B-Res
Quantification and measurement of habitability	B-Eng
On-orbit maintenance	B-Eng
Physiologic monitoring equipment	B-Eng
Water-system bacteriological control and monitoring	B-Env
Low partial-pressure CO <sub>2</sub> removal	B-Env
Atmosphere-leak location	B-Env
Reverse osmosis for wash and condensate water recovery	B-Env
Solar collector	B-Env
High-density magnetic recording	IS
Multipurpose displays	IS
Integrated display techniques	IS
Advanced electronic packaging and installation techniques	IS
Software reliability	IS
Long-life pressure cabins	MS
Docking systems	MS
Meteor impact on biaxially stressed materials	MS
On-board sensor alignment, calibration, and maintenance	C

Table 9  
ADVANCED DEVELOPMENT SRT ITEMS (Continued)

SRT Title	Technology Panel
Solar-cell energy-wheel system	C
Biowaste resistojet (engine and system)	C
Maintenance, resupply, propellant transfer of N <sub>2</sub> H <sub>4</sub>	C
Optical fine pointing of manned space experiments	C
Waste collection and sampling	B-Res
On-orbit cleaning, recoating, servicing, and calibration of optical elements	EI

Legend:

P	= Power	B-Res	= Bioresearch
IS	= Information System	B-Eng	= Bioengineering
M&S	= Materials and Structure	B-Env	= Bioenvironment
C	= Control	EI	= Experiment Integration